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AusIMM**

Abstract Volume

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**THE TOPOGRAPHIC GRAVITY CORRECTION COMPUTED BASED ON
THE 2-D DIGITAL ROCK DENSITY MODEL OF NEW ZEALAND**

A. Abdalla¹, J. Mikuška², I. Marušiak², R. Tenzer¹

¹National School of Surveying, University of Otago, Dunedin, New Zealand.

²G-trend. s.r.o., Bratislava, Slovakia
abdah305@student.otago.ac.nz

The mean density of the upper continental crust 2670 kg/m³ is often assumed in geological and gravity surveys, geophysical exploration, gravimetric geoid modelling, compilation of regional gravity maps, and other applications. The digital geological maps of New Zealand (QMAP) combined with the rock density samples from the national rock catalogue PETLAB and supplementary geological sources were recently used to generate the first 2-D digital rock density model of New Zealand.

In this study we facilitate the 2-D digital rock density model and the high accuracy and resolution regional and global digital terrain models to calculate the topographical gravity correction. The computation is realized at the study area of New Zealand. The results are analyzed and compared with the corresponding values of the topographical gravity correction calculated using only the constant density of 2670 kg/m³. In both cases, the spherical approximation to the problem is adopted. The comparison of results shows significant differences in the computed values of the topographical gravity correction particularly at the locations of computation points in mountainous regions with a variable geological structure.

The computed values of the topographical gravity correction are further compared with the simple and complete Bouguer gravity corrections calculated for the planar approximation of the Earth's surface. The practical aspects of using the planar and spherical topographical gravity corrections are discussed.

DISCOVERY OF CRETACEOUS GREYWACKE ON GREAT BARRIER ISLAND

C. J. Adams¹, H.J. Campbell², N.Mortimer¹

¹GNS Science, Crown Research, Private Bag 1930, Dunedin 9020

²GNS Science, Avalon, PO Box 30-368, Lower Hutt 5040
h.campbell@gns.cri.nz

Provenance studies relating to the basement sedimentary rocks of New Zealand and broader Zealandia continue to throw up interesting new surprises. Not least is the discovery or recognition of Early Cretaceous greywacke on Great Barrier Island, located some 100 kilometres east of Auckland City in the Hauraki Gulf.

The basis for this claim is the interpretation of detrital zircon age patterns for several greywacke samples collected on the coast of northern Great Barrier Island. We deliberately collected these samples proximal to previously known molluscan macrofossil localities. Interestingly, the fossils were interpreted as Late Jurassic, an age that is clearly at variance with the youngest detrital zircon ages which are demonstrably Early Cretaceous.

What does this mean? How can these two different age determinations be reconciled? In this instance, we favour the zircons and consign the fossils therefore, to a younger Early Cretaceous age. Needless to say, this has repercussions for the biostratigraphic age ranges of the fossils concerned.

Curiously, an identical situation involving similar if not identical species of molluscan macrofossils has been recognised in New Caledonia (see Cluzel et al. 2010: *Journal of Geology* 118: 381-397). Early Cretaceous 'basement' rocks had not previously been recognised in New Caledonia.

The significance of the Great Barrier Island Early Cretaceous is explored in terms of our understanding of tectonostratigraphy and provenance of the original sediments involved.

**THREE CLOSELY-SPACED MONOGENETIC VOLCANOES IN THE SIERRA
CHICHINAUTZIN VOLCANIC FIELD, SOUTH OF MEXICO CITY: GEOLOGICAL AND
GEOCHEMICAL OVERVIEW**

J. Agustin-Flores¹, C. Siebe², M-N Guilbaud³

¹Massey University, Private Bag 11222, Palmerston North.

^{2,3}Instituto de Geofísica, UNAM, Coyoacán 04510, Mexico City.

kiaoranet@yahoo.co.nz

The geology and geochemistry of Pelagatos, Cerro del Agua, and Dos Cerros monogenetic volcanoes are described in this study. They are located in the NE sector of the Sierra Chichinautzin Volcanic Field, near Mexico City. Based on field work and aerial/satellite imagery interpretation, a geologic map was produced. Also, their morphometric parameters were estimated. Pelagatos (0.0017 km³) and Cerro del Agua (0.028 km³) scoria cones produced lava flows covering areas of 4.9 km² and 17.6 km² respectively. Dos Cerros is a lava shield (80.3 km²) which is crowned by two scoria cones: Tezpomayo (0.022 km³) and La Ninfa (0.032 km³). The eruptions of Cerro del Agua and Pelagatos occurred between 2500 and 14 000 yr BP. The Dos Cerros eruption took place close to 14 000 yr BP.

These volcanoes are characterized by olivine-hypersthene normative, basaltic andesite and andesite rocks with porphyritic, aphanitic, and glomeroporphyritic textures. Their mineral assemblages include olivine, clinopyroxene, and orthopyroxene phenocrysts (≤10% vol.) embedded in a trachytic groundmass. Due to their high Cr and Ni contents, and high Mg#, Pelagatos rocks are considered to be derived from primitive magmas, hence the importance of this volcano for understanding petrogenetic processes in the region. Major/trace element abundances and petrography of products from these volcanoes indicate a certain degree of crystal fractionation during ascent to the surface. However, the magmas that formed the volcanoes evolved independently from each other and are not cogenetically related. REE, HFSE, LILE, and isotopic (Sr, Nd, and Pb) compositions point towards a heterogeneous mantle source that has been metasomatized by aqueous/melt phases from the subducted Cocos slab. There is no clear evidence of important crustal contributions in the compositions of Pelagatos and Cerro del Agua rocks. The Sr isotopic composition of Dos Cerros, however, may indicate a small degree of crustal contamination.

GEOHERMAL RESOURCE ASSESSMENT FOR THE ISLAND OF EFATE, VANUATU

Kenneth B. Alexander¹

¹ Sinclair Knight Merz, Carlaw Park, 12-16 Nichols Lane, Parnell, Auckland.

kalexander@skm.co.nz

KUTH Energy is evaluating the development of a geothermal system or systems on the island of Efate, Vanuatu. Several previous studies have focused on identifying the source of the numerous hot springs at Takara along the northern coast of Efate and the springs in the Teuma Graben. However, the temperature, chemistry, size, and exact location of this system were not determined with any certainty.

SKM completed a new assessment of the Efate geothermal system(s) based on the available historic geoscientific information and the results of fieldwork completed in August 2010, including geological, geochemical, and geophysical data collection and interpretation. The key conclusions are:

- The geology of Efate is relatively straightforward consisting of two major volcanic formations overlain by reef-forming limestone.
- The extensive hydrothermal alteration and localised mineralisation in the Mt Fatmalapa area appears to represent an area of former geothermal activity.
- Maximum water temperatures were 74°C at Takara Springs and 60°C at Mid-Teuma Springs, consistent with historic data.
- Analytical results for Takara Springs indicate that the hot water is almost entirely sea water. The high flow rate and lack of steam or steam-heated features in the area suggest that deep temperatures are probably no more than 190°C and 150°C is more likely. At Mid-Teuma Springs, the results of the recent sampling indicate source temperatures in excess of 200°C with a probable non-seawater source.
- There are still ambiguities in the conceptual model of the Efate geothermal system(s) but the most likely possibility is that the Takara Springs represent an isolated, seawater-recharge system with a local heat source and temperatures probably not over 190°C at economically drillable depth. The Teuma Graben springs have a separate, hotter freshwater source. The location of that source is unknown.

MODELLING TRACER TRANSPORT IN GROUNDWATER AQUIFERS

A. Ali & R. McKibbin

Inst. of Inf. and Math. Sciences, Massey University, PB 102-904 NSMC, Auckland
amjadfarman@yahoo.com

Chemical species such as tracers or dissolved pollutants are dispersed by water flowing within a permeable matrix. The species move not only "down-stream", but also spread in all directions. The rate of dispersion depends on the permeability structure and the fluid speed.

Generally, groundwater systems have layered structures determined by different events in the geological processes that formed them. The layers in a system have different physical properties, and their thicknesses are not uniformly constant. The advection-dispersion equations that model the fluid and species transport then have coefficients that depend mainly on depth, but with a layer composition that changes with horizontal distance.

Here, the matrix and flow parameters that contribute to the coefficients in the partial differential equations are assumed constant within each layer, but can be different in each of the various layers. The layer thicknesses are assumed small compared to the lateral extent of the aquifer, and their interface slopes are also small. The steady-state fluid flow and the associated pressure distribution may be readily computed. The vertically-averaged pollutant concentration within each layer varies in the plane of the flow. Lateral changes in concentration within the layers may occur by advection and dispersion, and also by transfer of the pollutant across the layer interfaces when the concentrations within adjoining layers are not equal. The resulting set of linear pde's is thus coupled by fluid and species mass flux continuity requirements at the layer interfaces.

In some cases, full or partial analytic solutions for the species concentration can be found, thereby saving computational effort. A layered system may also be used as an approximate realization of an aquifer with properties that vary smoothly with depth, allowing semi-analytic solution of realistic physical problems where dispersion takes place in all directions. Some illustrative results will be presented.

CRYSTAL-SPECIFIC INVESTIGATIONS IN EARLY PHASES OF THE 27 KA ORUANUI SUPERERUPTION, TAUPO VOLCANO

A.S.R. Allan¹, C.J.N. Wilson & J.A. Baker

¹SGEES, Victoria University of Wellington, PO Box 600, Wellington.
aidan.allan@vuw.ac.nz

Crystal-specific investigations of pumices from early phases (1 to 3) of the 27 ka Oruanui eruption (530 km³ magma) have yielded new insights into the lead-in and beginnings of the world's youngest supereruption. Geothermobarometric measurements from hornblende yield results that are consistent within uncertainty of previous determinations. The high-silica rhyolite has a pronounced mode at a magmatic temperature of around 770 °C with corresponding pressure estimates between 100 and 200 MPa, but there is also a tail of grains recording higher temperatures and pressures (to 920 °C and 270 MPa). This tail is inferred to reflect efficient mixing of the Oruanui magma body shortly prior to eruption and stirring in of crystals from deeper levels. A newly recognised magma type, represented by moderately crystal-rich biotite-bearing pumices, is found in the deposits of phases 1 to 3. These pumices, consistently denser than the dominant biotite-free pumice previously documented, comprise typically 2 to 4 wt % of the pumice lapilli population, with higher abundances in the top-most layers of fall units 1 and 2 (~25% and 12%, respectively). Geothermobarometry of these biotite-bearing clasts suggests a significant component of the crystals were sourced from shallower levels than is inferred for 'normal' Oruanui pumices (as low as 65 MPa, equivalent to ~ 2.5 km depth). The low pressure amphibole phase cummingtonite is also present in these pumices as inclusions in, or having been partially replaced by, Mg-hornblende. Melt inclusion and groundmass glass compositions show that the biotite-bearing magma exchanged crystals and melt with the 'normal' dominant-volume Oruanui rhyolite. The question of whether the Oruanui biotite-bearing pumices represent a shallow level plutonic cap to the Oruanui magma body, or laterally emplaced magma fed from the magma system that fed a 28 ka biotite-bearing tephra and rhyolitic dome complex to the northeast, is currently under investigation.

**LIQUEFACTION IN THE TAI TAPU – GREENPARK AREAS, SELWYN DISTRICT
FOLLOWING THE 4 SEPTEMBER DARFIELD (CANTERBURY) EARTHQUAKE:
PATTERNS, SOURCES OF LIQUEFIABLE MATERIALS, AND REMEDIATION**

P. Almond¹, F. Shanhun¹, A. Eger¹ & T. Wilson²

¹Dept of Soil and Physical Sciences, Lincoln University, PO Box 7647, Christchurch.

²Dept of Geological Sciences, University of Canterbury, Christchurch.

peter.almond@lincoln.ac.nz

Liquefaction damage in the Tai Tapu-Greenpark area of Selwyn District, south of Christchurch City, was concentrated in a 40 – 250 m-wide, semi-continuous swath broadly following the current Halswell River channel. Lifestyle and small block pastoral farms were affected. The liquefaction appears to be closely associated with Tai Tapu and Kaiapoi soils of the Selwyn-age surface (<300 yr), both imperfectly to poorly drained soils underlain by sands and a shallow groundwater table. Ejected sand was almost invariably very fine and fine with a small silt component and usually grey in colour, although minor areas were olive brown.

Detailed auger drilling along a 150 m-long transect across an area with no, light and severe liquefaction damage showed un- and lightly damaged areas had liquefiable sands beneath silty clays incorporating a peat layer. The heavily damaged areas were predominantly sandy throughout and lacked the peat layer. The stratigraphy suggests highly liquefaction-prone areas are associated with an infilled river channel. Soil pits revealed no unequivocal evidence of prior, significant liquefaction.

Liquefaction damage included ejection of sand, forming sand volcanoes and sand ridges, as well as steep-sided ‘blisters’ up to 40 cm-high where sand was injected into the upper parts of the soil without rupturing the soil surface. Both kinds of damage presented problems for landholders who rely on the pastures for grazing and supplementary feed. Sand erupted at the surface, while not ‘toxic’, buried grass and reduced the area of pasture production, and the microtopography formed by this kind of damage and the ‘blisters’ made paddocks unsuitable for harvesting machinery.

We trialled a range of methods for rehabilitating paddocks and found spreading of ejected sand and cultivation by rotary hoe followed by drilling to be the best option for re-establishment of pasture. ‘Blisters’ were readily flattened by rotary hoeing then power-harrowing.

AMBIENT NOISE ANALYSIS – A MICROSEISMIC TOOL FOR DETECTING TREMORS

M. Alvarez

¹IESE, University of Auckland, 58 Symonds St., Auckland

m.alvarez@auckland.ac.nz

The recently observed phenomena of episodic aseismic slip accompanied by non-earthquake like tremors in the Cascadia region of Western United States is well characterized by analysing ambient noise on high quality seismic stations. In this study we analyse over 600 days of continuous recording from over 78 evenly spaced USArray seismic stations in Western Washington.

We compare the background noise levels using McNamara’s probability density function (PDF) analysis between various seismic station designs. There are three differing standardized seismic stations which were used in this study; the Transportable Array (TA), 2. The Flexible Array (FA), and 3. the Plate Boundary Observatory downhole (PBODH). The TA stations are constructed in 2 m deep, 1 m diameter cylindrical vaults with insulated broadband sensors placed on concrete pads. The FA vaults are 1 m deep, 30 cm diameter cylindrical vaults. The PBOBH stations are short-period sensors emplaced in 100 meter boreholes. Our results demonstrate that the much improved signal to noise levels achieved with the PBOBH sensors make this seismic station design much more effective at recording the faint tremor episodes.

We propose that ambient noise analysis may be very effective in detecting and characterizing tremors in geothermal areas. Tremors are thought to be a result of ‘de-watering’ of the down going oceanic crust. As such, subterranean circulating fluids should be an observed phenomena in active geothermal areas.

**A COMPARISON OF BURIED ANDESITES AT NGATAMARIKI AND ROTOKAWA
GEOTHERMAL FIELDS, TAUPO**

**L. C. V. Andersen¹, R. M. Briggs¹, A. Pittari¹, G. Bignall², A. J. Rae², L. Price³ &
C. Boseley³**

¹Dept. of Earth and Ocean Sciences, University of Waikato, Private Bag 3105,
Hamilton 3240.

²Wairakei Research Centre, GNS Science, Private Bag 2000, Taupo 3352.

³Mighty River Power Limited, 283 Vaughan Road, Rotorua 3010.
lcv2@waikato.ac.nz

The Rotokawa and Ngatamariki geothermal systems, are hosted by hydrothermally altered Quaternary andesitic, dacitic and rhyolitic volcanics resting on Mesozoic Torlesse greywacke basement, and covered by lacustrine sediments and surficial deposits. Andesitic lava and breccia (> 2 km thick) below 1 km depth at Rotokawa is an important production aquifer for geothermal power due to its interconnected fracture permeability. Exploration drilling at Ngatamariki has revealed andesite at several depth intervals, the youngest having an ⁴⁰Ar/³⁹Ar date of 1.2 Ma, interlayered with ~1 km of ignimbrite. The petrographical and geochemical characteristics of the Ngatamariki and Rotokawa andesites are the focus of this study.

Rotokawa andesite is a massive to flow-banded, fine-medium grained porphyritic lava with primary plagioclase (An₅₁₋₈₂), augite and hypersthene in an aphanitic groundmass. Accessory minerals are biotite, hornblende, quartz and Fe-Ti oxides. The Ngatamariki andesite has primary plagioclase (An₅₄₋₈₂), augite and hornblende phenocrysts. Intercalated breccias contain andesite, minor rhyolite and greywacke lithics in a fine grained matrix. Hydrothermal alteration is propylitic, albeit with minor potassic or argillic mineralogy resulting from variable conditions within the thermally-evolving reservoirs. The andesite is commonly veined and/or has a vuggy texture.

XRF analyses, particularly plots of immobile element data, e.g. Ti vs. Zr, Y vs. Zr, have been used to fingerprint the hydrothermally altered volcanics, and infer the intensity of fluid-rock interaction. The Ti/Zr ratio in Rotokawa andesite ranges from 41 to 58 whereas in the Ngatamariki andesite it is 17 to 39 (with one outlier of 49 from a well which is closest to Rotokawa, and several hundred metres deeper than other Ngatamariki samples). Chemical data, combined with inferred stratigraphic relationships suggest Rotokawa andesite derives from an older, basaltic andesite composite cone volcano, compared to a younger dacite/andesite volcanic centre at Ngatamariki.

**ASSESSING THE EFFECTS OF SEDIMENTARY ARCHITECTURE AND SUB-SEISMIC
FAULTING ON FLUID FLOW IN DEEPWATER CLASTIC RESERVOIR INTERVALS:
TARANAKI BASIN, NEW ZEALAND**

Malcolm J. Arnot¹ and Julian Strand²

¹GNS Science, PO Box 30368, Lower Hutt.

²CSIRO Petroleum, Perth, Australia.
m.arnot@gns.cri.nz

Late Miocene basin-floor turbidite fans of the Mount Messenger Formation, superbly exposed in cliff sections on the west coast of the North Island, New Zealand, represent an excellent analogue for deep-water turbidite petroleum reservoirs here and elsewhere around the world. A high-resolution multidisciplinary examination of the structural and stratigraphic elements of the exposures provided input for reservoir modelling and flow simulation sensitivity studies. These studies were aimed at assessing the relative impact of complex sub-seismic faulting, fault rock properties and sedimentary heterogeneity on fluid flow in reservoirs of this kind. A number of coarse- and fine-scale reservoir models were created with a range of fault densities, sand/shale amalgamation ratios and fault rock properties. In addition, two methods were assessed, Shale Gouge Ratio (SGR) and Clay Smear Potential (CSP) for incorporating fault properties into the simulation models. A total of 108 fine-scale models and 108 coarse-scale models were constructed and flow simulation runs performed. For this sensitivity study the dynamic reservoir properties (e.g. relative permeability, capillary pressure curves and fluid PVT properties) were kept constant.

Results for this study show that the amalgamation ratio of the sands/shales and the density of minor (sub-seismic) faults were the significant parameters in controlling oil recovery. The amalgamation ratio was the primary parameter with the density of minor faults acting as the secondary parameter affecting fluid flow. The SGR and CSP methods for incorporating fault rock properties in the simulation model did not show significant differences in the fluid flow behaviour across the minor faults.

ANALYSIS OF INTERFERENCE TEST DATA USING TOUGH2 RESERVOIR SIMULATOR

Ali Ashat¹, Sutopo¹ & Agni M. Sumbaga¹

¹Geothermal Lab.-Institute Technology of Bandung, Indonesia.
labgeothermal@yahoo.com

Interference test has been carried out at a geothermal field NM in North Sumatera, Indonesia. The objectives of the test were to have a picture of an initial numerical reservoir model and to determine an important reservoir parameter that is permeability thickness.

The test was carried out in 4 phases which involved 1 production, 1 injection and 2 observation wells. Status of wells (production, injection and observation) was interchangeable which distinguished between one to the other phase. Pressure responses were analysed numerically using TOUGH2 reservoir simulator. The system between production, injection and observation wells was evaluated by 2 models. The first model was a 2D model in X-Y direction while the second one was a 3D model in X-Y-Z direction. Analytical Theis solution is firstly applied to get values of permeability thickness for initial estimates. Reservoir parameters such as rock porosity and permeability have been varied to get a model which is able to simulate the actual pressure responses. A good agreement between the models and the observed data was obtained and the values of inter-well permeability thickness can be determined.

GEONET's RAPID RESPONSE TO THE DARFIELD M_w7.1 EARTHQUAKE

C. Ashenden¹ & the GeoNet Team¹

GNS Science, PO Box 30368, Lower Hutt, Wellington, New Zealand
c.ashenden@gns.cri.nz

At 4:35am on Saturday, 4th September 2010 a magnitude 7.1 earthquake shook the Canterbury region. The earthquake was centred 10km southeast of Darfield, with a focal depth of 10km. The earthquake was the most damaging earthquake since the 1931 Hawke's Bay earthquake, therefore it was necessary for the GeoNet team to initiate a rapid seismic response.

This initial response consisted of a Wellington team deployed to install seismometers and accelerometers to better record the aftershock sequence. 10 Lenartz short period seismometers and 3 ETNA strong motion accelerometers were installed around rural Canterbury 1-2 days after the main shock. The strong motion accelerometers were installed as close to the fault trace as possible, while the short period sites were placed around the aftershock 'cloud'. The strong motion accelerometers are instruments that are triggered to record by significant ground shaking. The short period seismometers record continuously, however during a significant aftershock, shaking could reach the maximum recordable amplitude, and as a result, accurate earthquake magnitudes would not be calculable. The short period equipment was taken out 25 days after their deployment, while the strong motion instruments will be left for 1-2 months. These data will complement data from the permanent GeoNet network of seismometers and accelerometers around the region.

Following the initial instrument deployment, a further 11 CUSP strong motion accelerometers were installed in buildings in Christchurch and around rural Canterbury in the week following the earthquake. These data from urban sites will be used to study building responses to a range of ground conditions including the presence and absence of liquefaction, and the amplification of shaking in multistorey buildings. The rural site data will be used for tomography studies to gain a 3D understanding of the velocity structure of the subsurface.

ERUPTION STYLE AND EMPLACEMENT PROCESSES OF NGONGOTAHA DOME, ROTORUA

P. A. Ashwell¹, B. Kennedy¹, F. von Aulock¹, J. Cole¹

¹Department of Geological Sciences, University of Canterbury, New Zealand
paul.ashwell@pg.canterbury.ac.nz

Lava domes are commonly associated with large, silicic calderas which are well developed in the Taupo Volcanic Zone. Particular styles of lava dome eruption can pose a grave danger to the surrounding area, yet the transitions in eruption style during dome formation are poorly understood. The internal structure of the c.220 ka Ngongotaha Dome was mapped to identify specific features to improve our understanding of eruption styles. Internal structural data such as flow banding, lithology changes, and porosity and permeability measurements have been used to unravel the history of the eruption of the dome. Ngongotaha Dome is a high silica, low crystal content dome, showing concentric rhyolitic lithologies that are cross cut by flow banding. These lithologies range from a microcrystalline, strongly flow banded rhyolite (with low porosity) in the centre, to less banded, highly spherulitised obsidian and a carapace of finely vesicular pumice (with higher porosity). Spine-like structures pierce into the carapace, are bound by vertical shear zones, and contain vertical flow banding perpendicular to dome outline. We believe that the dome extruded as a series of vesiculated, high viscosity ($\log \eta = 10.45$ Pa/s with 0.25wt. % H₂O) lobes, each of which was comprised of several lava pulses emplaced as exogenous flows. The dome may have initially erupted as finely pumiceous and this texture is preserved in the outer carapace due to rapid cooling. Slower cooling in the centre of the dome allowed vesicles to collapse, destroying porosity and may have produced space for continued internal endogenous injections which produced the convoluted flow bands. Further lava emplacement produced spines. Local spherulite growth and large scale dehydration recrystallisation started shortly after eruption, and continued after the dome had cooled past the glass transition temperature. The final magma injection phase produced late stage, less devitrified obsidian dykes where both primary vesiculation and collapsed bubbles have been identified.

HYDROTHERMAL GEOCHEMICAL INTERACTIONS OF THE SUBSURFACE RESERVOIR IN THE NGATAMARIKI GEOTHERMAL FIELD, NEW ZEALAND

L. Atkinson¹, Travis Horton¹, Christopher Oze¹

¹Dept. of Geological Sciences, University of Canterbury, Private Bag 4800,
Christchurch
leematkinson@gmail.com

Geothermal energy is an underutilized resource due to significant costs associated with drilling and exploration. Improving geothermal resource exploration success may be achieved by assessing and coupling the geochemistry and mineralogy of both deep subsurface to near surface processes. Here, we evaluate both isotopic and geochemical reaction pathways of fluid-rock interactions in hydrothermal systems located in the Ngatamariki Geothermal Field (Taupo Volcanic Zone, New Zealand). Measured homogenization temperatures obtained from secondary quartz are consistent with those from hydrothermal carbonate in previous Ngatamariki studies. Using fluid inclusion derived homogenization temperatures combined with secondary $\delta^{18}\text{O}$ values, measured $\delta^{18}\text{O}$ values in Ngatamariki samples indicate fluids are derived from a magmatic source with varying amounts of meteoric water input. Thermodynamic modelling based on field observations and measurements are currently being utilized to evaluate how metasomatic reactions involving both silicates and carbonates affect the heat flow as well as the porosity of the hydrothermal system. Overall, the results of this study will enhance current drilling strategies to enable better targeting of the geothermal resource.

PAGES – PAST GLOBAL CHANGES PROJECT

P. C. Augustinus¹

¹School of Environment, University of Auckland, PB 92019, Auckland, New Zealand
p.augustinus@auckland.ac.nz

The Past Global Changes (PAGES) is one of the core projects of the International Geosphere-Biosphere Programme (IGBP). PAGES is an international research initiative that supports all paleoenvironmental and paleoclimate research efforts directed at securing a quantitative understanding of natural and human-induced variations of the Earth system in the past, in order to make sound predictions of future climate, environment and sustainability. PAGES also provides a forum for scientists to discuss and interpret ice, ocean, and terrestrial paleoclimate records and modelling results, and foster the development of internationally accessible data archives.

The scope and focus of paleoscience research is continuously evolving; as questions are answered, others are raised. To keep up to date with these advances, PAGES revised the scope of its science structure. It now addresses four Foci and four Cross-Cutting Themes (CCT). Each Focus covers a set of questions that is of prime importance to the global community. The CCT are more general in their scope and are of fundamental relevance to all Foci and to paleoscience in general.

Focus 1: climate forcings. This Focus fosters production of improved, extended, and consistent time series of climate forcing parameters, both natural and anthropogenic.

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For further information, including joining an existing programme and suggesting a new initiative, go to: <http://www.pages-igbp.org>

THE LAST GLACIAL CYCLE VIEWED FROM AUCKLAND MAAR LAKES

P. C. Augustinus¹, D. D'Costa¹, T. Stephens¹, D. Atkin¹, U. Cochran², P. A. Shane¹
&
J. Wilmshurst³

¹School of Environment, University of Auckland, PB 92019, Auckland, New Zealand

²GNS Science, PO Box 30368, Lower Hutt, New Zealand

³Landcare Research, PO Box 40, Lincoln 7640, New Zealand
p.augustinus@auckland.ac.nz

High-resolution Late Quaternary paleoclimate archives are preserved in the lake sediment records contained in several maars from the Auckland Volcanic Field in northern New Zealand. Tephrochronology, AMS ¹⁴C and Ar/Ar-based chronostratigraphies were developed for several paleolakes that contain laminated sediment records spanning much of the last glacial cycle. A multi-proxy approach was taken to constructing reliable records of local and regional paleoenvironments including: pollen and diatom paleoecology, environmental magnetism, grain size, XRF geochemistry, TOC, TN, TS, organic matter $\delta^{13}\text{C}$, $\delta^{15}\text{N}$ and δD , as well as $\delta^{18}\text{O}$ in biogenic silica. Pollen and diatom analysis of records spanning the last ca 50 ka show marked vegetation changes that reflect orbital forcing, although diatoms suggest significant hydrological changes that are not reflected in the pollen. Furthermore, application of a pollen-based MAT model indicates the timing and magnitude of short duration warming events of up to 4°C that appear to be in phase with Antarctic Isotope Maxima/Antarctic Interstadials from the EPICA Dronning Maud Land and Byrd ice cores respectively.

Reduction of forest with expansion of grass/shrubland at the start of the Last Glacial Coldest Period (LGCP) ca 28.5 ka BP is accompanied by cool, dry and windy conditions, although the situation is complex with multiple brief warmer phases punctuating the LGCP. Post-glacial warming commenced ca 18 ka BP and is reflected in several proxies, although the pollen record does not display the marked changes displayed in many of the other proxies during the Last Glacial-Interglacial transition and Holocene. The multi-proxy approach used here has produced one of the most complete, well-dated and high-resolution paleoenvironmental records spanning the INTIMATE (INTEgration of Ice-core, MARine and TERrestrial records) time-scale from the mid-latitudes of the Southern Hemisphere, and has implications for the nature, timing and forcing of climate change in the Southwest Pacific region.

GEOCHEMICAL TRACERS: TOOLS FOR RESERVOIR CHARACTERISATION IN GEOTHERMAL SYSTEMS

B. Ayling^{1,2}, **P. Rose**¹, **K. Leecaster**¹, & **M. Bartl**³

¹Energy & Geoscience Institute, University of Utah, Salt Lake City, Utah, USA

²Geoscience Australia, GPO Box 378, Canberra, ACT 2601, Australia

³Department of Chemistry, University of Utah, Salt Lake City, Utah, USA

b.ayling@egi.utah.edu

Geochemical tracers have provided key roles in the characterisation of vapour and liquid-dominated geothermal reservoirs worldwide, providing information on inter-well connectivity, recharge areas, swept pore volumes, and reservoir temperatures. This paper will present an overview of geochemical tracers recently developed (or in development) at the University of Utah, with examples of field and/or laboratory tests and interpretation where possible.

UV-fluorescent polyaromatic sulfonates (naphthalene sulfonates) have been used to map fluid flow pathways in liquid-dominated geothermal reservoirs in conventional and Engineered Geothermal Systems around the world (including Ohaaki) over the last 10 years. There are approximately 9 compounds in the polyaromatic sulfonate family that have been identified as suitable geothermal tracers, each of which is thermally stable, environmentally benign, relatively inexpensive and easily detectable in low concentrations (200 ppt) using conventional high-performance liquid chromatography (HPLC) with fluorescence detection.

New research is exploring potential compounds that are reversibly sorptive and that can provide information on relative changes in fracture surface areas (and therefore heat exchange areas) in engineered geothermal reservoirs. Candidate compounds are currently being tested in the laboratory for thermal stability and adsorptivity using batch autoclave reactors and a flow reactor respectively. Field tests are planned at a number of sites in the western USA in the near future.

Additionally, current research is assessing quantum dots that fluoresce in the near-infrared or visible range as potential geothermal tracers. Quantum dots are small crystallites (1-10 nm in diameter) of semiconducting compounds (e.g. CdSe) with tunable electronic and optical properties and high fluorescence quantum yields. Future work will investigate the fabrication of quantum dots that are reactive through coating the CdSe cores with reactive compounds.

PRELIMINARY FINDINGS OF HYDROGEN SULFIDE IN ROTORUA, NEW ZEALAND, AND WHERE TO NEXT

J. Barclay

Atmospheric Studies Group, TRC, 650 Suffolk Str, Wannalancit Mills, Lowell, MA, USA

678 Remuera Road, Remuera, Auckland, New Zealand

jbarclay@trcsolutions.com

There are few cities in the world that lie directly atop an active geothermal field where its population is exposed to chronic high ambient levels of hydrogen sulfide (H₂S). The city of Rotorua, New Zealand, is the only one. Its hydrothermal system, some ~25km², underlies the entire area of the city and extends north into Lake Rotorua. The city lies at the south end of a Caldera, a nearly circular, infilled depression of 20 km x 21 km. The meteorology is complicated, exacerbated by the complex terrain surrounding the city, the lake and the coast, some 30km to the east.

Almost all of the atmospheric H₂S comes from three active geothermal areas within and around the immediate city, comprising about 1800 recognised surface emission features. Other significant sources include home heating vents and the lake. The natural features are monitored regularly for changes in characteristics, such as chemistry, temperature and alkalinity, but neither emissions, plume characteristics, dispersion nor transformation of H₂S in the atmosphere from these sources has ever been quantitatively evaluated.

Sophisticated meteorological and dispersion modelling has been undertaken to attempt to quantify and understand atmospheric H₂S around Rotorua. This has presented numerous challenges. One of the major difficulties in quantifying H₂S over Rotorua has been lack of any upper air data, which has meant reliance on numerical meteorological models to develop the 3D wind field. Further, emission sources, such as mudpools, fumaroles, eruption craters, etc., are highly variable with respect to emission rates, temperature, exit velocity, and size. Also, the geothermal field is constantly pulsing, so that emissions and plume characteristics of a source are never constant. Other considerations are the temporary effect of rainfall, which reduces H₂S emissions, oxidation and evaporation of H₂S, the longevity of H₂S in Rotorua's relatively clean atmosphere, and the role of the ambient wind in agitating H₂S from the lake--arguably one of the biggest sources.

This study has raised more questions than provided answers. Future work should include real measures of upper air data within Rotorua and collection and measurement of surface air and lake water samples for H₂S under various ambient wind speeds.

RECOMMENDATIONS FOR MODELING GEOTHERMAL PLANT NCG VENTS IN CALPUFF BASED ON COMPUTATIONAL FLUID DYNAMICS SIMULATIONS

J. Barclay, L. Schulman, C. Des Autels and D. Strimaitis

¹Atmospheric Studies Group, TRC, 650 Suffolk Str, Wannalancit Mills, Lowell, MA, USA

jbarclay@trcsolutions.com

In order to meet NZ Air Consent Guidelines, exhaust emissions from Geothermal power plants are required to be assessed to consider the ground level impacts of non condensable gases downwind (NCG). NCG gases from Geothermal plants typically include array's of exhaust fans on top of a building which may or may not be solid.

This paper examines the rise and dispersion of NCG vent exhausts and how they interact with the warmed air of the fans. The goal of the study was how to model the NCG exhausts within the CALPUFF model. Although the NCG vents are essentially point sources, modeling the exhaust plumes from these vents presents two challenges.

Firstly, the NCG vents are not isolated point sources and are usually embedded within the array of exhaust fans of the air condenser. Typically one vent may service each array of fans. The discharge volume of the exhaust fans may be orders of magnitude larger than the discharge from the NCG vent even though the NCG exhaust is hotter. The buoyancy flux, a measure of the potential plume rise, may be two orders of magnitude larger from the exhaust fans.

The second challenge is that the air condenser's may not be a solid building. On porous buildings air is drawn under the building and exhausted through the fan arrays. If the air condenser building is assumed solid, the model would assume air could only flow over and around the condenser and would create a downwind turbulent wake that could potentially downwash the exhaust. This would not be realistic.

Results of a study using a computational fluid dynamics (CFD) model and for an air condenser building that is porous show that the NCG vent exhausts are mixed within and have the same plume rise as the buoyant line source formed by the condenser fan exhausts. By breaking the lines of 66 condenser fans, 3 deep and 22 long into 22 individual line sources will account for more accurate final plume rise. Further, to account for the porous air condenser structure, where air can flow underneath, modification to the vertical dimension of the solid portion of the condenser structure was conducted in the model allowing less initial dilution and greater plume rise.

VISUALISING THE GEOTHERMAL RESERVOIR – MIGHTY RIVER POWER LIMITED'S APPROACH TO 3D GEOLOGICAL MODELLING.

C. Bardsley

Mighty River Power Limited, PO Box 245, Rotorua, New Zealand.
candice.bardsley@mightyriver.co.nz

A key aspect to the successful operation of a geothermal power station is the ability to understand and visualise the geothermal reservoir upon which the power station depends. Mighty River Power (MRP), like other geothermal power companies, has relied upon standard 2D methods of visualisation including surface mapping and cross section construction, which is often difficult to tie together in the complex setting of a geothermal reservoir.

During the past year, MRP branched out into 3D visualisation of its geothermal fields, utilising the 3D modelling package MVS (Mining Visualisation Systems). While this program was designed initially for the petroleum and mining industry, it provides the tools to do the type of 3D analysis and visualisation required within the geothermal industry. A key reason why MRP decided to choose MVS as its 3D modelling package was the seamless interaction with ESRI's ArcGIS.

Construction of 3D geological models for the Kawerau, Mokai, Rotokawa and Ngatamariki fields is under way, with both Kawerau and Rotokawa well advanced. The initial goal of these models is to build a robust and accurate geological model from as unbiased a perspective as possible and provide a visual record for comparison and discussion. Temperature data, feed zone locations, alteration horizons, enthalpy data, flow rates and seismic data are just some of the parameters which will be added to the models in the coming months – all of which will be able to be visualised and analysed within the geological framework.

The ability to improve the understanding of the reservoirs by being able to visually depict the known information and extrapolate this into areas where there is little or no data is a key improvement over standard methods. Also key is the ability to visually describe to other stakeholders what is occurring within the reservoir and hence provide confidence to any future planning.

FRACTIONATION PROCESSES DOMINATE IN THE GENERATION OF SILICIC MAGMAS FROM FOUR KERMADEC ARC VOLCANOES

S.J. Barker¹, C.J.N. Wilson¹, M.D. Rotella¹, J.A. Baker¹, R.J. Wysoczanski², M.A. Millet¹, I.C. Wright³

¹SGEES, Victoria University of Wellington, New Zealand

²National Institute of Water and Atmospheric Research, Wellington, New Zealand

³National Oceanography Centre, Southampton, UK
smnbarker@gmail.com

Recent work has shown that silicic volcanism can be abundant in intra-oceanic subduction settings, and is often associated with large explosive caldera forming eruptions. Several major petrogenetic questions arise from the origin and eruption of large silicic magma bodies at relatively simple subduction settings. We have investigated the geochemistry of pyroclasts collected from four volcanoes along the Kermadec arc; a relatively young (<2 Myr) oceanic subduction zone. Raoul, Macauley and a newly discovered volcano in the northern Kermadec arc, and Healy volcano in the southern Kermadec arc have all erupted dacite-rhyolite pumice within the last 10 Kyr. Examination of whole-rock, mineral and glass major and trace element chemistry reveals that evolved magmas can be generated through crystal fractionation and not by partial melting of amphibolite. Silicic magmas and co-eruptive mafic enclaves show sub-parallel REE patterns, and crystal zonation suggests that mafic and silicic magmas are closely related. However, distinctive crystal populations in both pumice samples and plutonic xenoliths suggest that many of the crystals did not grow in the evolved magmas, but were mixed in from other sources including gabbros and tonalites. Such open system mixing is ubiquitous in magmas from the four Kermadec volcanoes. Although crystallization is the dominant process driving melt evolution in the Kermadec volcanoes, the magmatic systems are open to contributions from both newly arriving melts and wholly crystalline plutonic bodies. Such processes occur in variable proportions between magma batches, reflected by the chemical variations observed between eruption units.

LATE HOLOCENE PALEO-EARTHQUAKE RECORDS OF THE SOUTHERN ALPINE FAULT AND FIORDLAND SUBDUCTION ZONE, NEW ZEALAND, BASED ON OFFSHORE SEDIMENT CORES

Philip Barnes¹, Helen Bostock¹, Helen Neil¹, Matthew Gosling², Lorna Strachan², Gary Wilson³, Angus King³

¹National Institute of Water & Atmospheric Research (NIWA), Private Bag 14901, Wellington, New Zealand.

²University of Auckland, School of Environment, Private Bag 92019, New Zealand

³University of Otago, PO Box 56, Dunedin, New Zealand
p.barnes@niwa.co.nz

Turbidite records obtained from seafloor sediment cores in zones of seismically active plate boundary deformation can be used to infer the return time for strong ground-shaking earthquakes, and in some cases the rupture extents of particular faults that have experienced earthquakes. We present preliminary results of a study of paleo-earthquakes beneath the offshore Fiordland margin, where strong ground shaking is associated largely with strike-slip earthquakes on the southern Alpine Fault and thrust earthquakes on the Fiordland subduction zone. We document late Pleistocene and Holocene earthquake-triggered turbidites over a 90 km length of the margin, and focus particularly on three Late Holocene (<3 ka) cores from near-shore strike-slip basins along the Alpine Fault. Analysis of the cores, including geotechnical logging, paleomagnetism, grain size, carbonate and radiocarbon dating of foraminifera, are used to identify and date the sand-silt turbidite deposits. Whilst the cores are short (<1.5 m), they contain 7-12 individual events, with return times of ~160 to 210 yrs. We discuss the spatial and temporal variability of the paleoearthquake records, and implications of the results.

DERIVATION OF DIRECT ON-FAULT SUBMARINE PALEOEARTHQUAKE RECORDS FROM HIGH-RESOLUTION SEISMIC REFLECTION PROFILES, COOK STRAIT, NEW ZEALAND: IMPLICATIONS FOR FAULT INTERACTIONS AND STRESS LOADING

Philip M. Barnes¹ & Nicolas Pondard^{1,2}

¹National Institute of Water & Atmospheric Research (NIWA), Private Bag 14901, Wellington, New Zealand.

² Present address: Willis Ltd, 51 Lime St, London EC3M 7DQ, United Kingdom
p.barnes@niwa.co.nz

Under favourable conditions, direct on-fault submarine paleoearthquake records can be derived from high-resolution seismic reflection profiles of active fault growth sequences. The most ideal conditions are when the long-term rate of sedimentation exceeds the rate of fault vertical displacement, and coseismic vertical increments of displacement and fault scarp development are preserved in the architecture of the growth sequence. In this case the interseismic period of sedimentation may comprise a post-seismic growth interval, covered by a uniformly thick sedimentation interval that developed after burial of the fault tip. Such intervals can be recognised on vertical displacement history curves, and from particular seismic stratigraphic relationships. In the generally less favourable situation where the long-term fault vertical displacement rate exceeds the sedimentation rate, it is still possible in some cases to recognise coseismic vertical displacements based on the specific architecture of the post-seismic growth sequence. We present a conceptual model, methodologies, and examples of paleoearthquake records for the offshore Wairau, Cloudy and Vernon faults in Cook Strait, New Zealand. We compile the offshore interpretations with onshore paleoearthquake records, and model Coulomb static stress loading, to investigate regional fault interactions.

ANTscape: ANTARCTIC PALEOTOPOGRAPHIC MAPS FOR THE LAST 100 MILLION YEARS

P.J. Barrett¹, J.E. Francis², G. Eagles³, K. Gohl⁴, S.S.R. Jamieson⁵, C.S. Siddoway⁶, D.S. Wilson⁷ and the ANTscape group

¹Antarctic Research Centre, Victoria University of Wellington, P.O. Box 600, Wellington

²School of Earth and Environment, University of Leeds, Leeds LS2 9JT, UK

³Department of Earth Sciences, Royal Holloway, University of London, Egham, Surrey, TW20 0EX, UK

⁴Alfred Wegener Institute for Polar and Marine Research, Postfach 120161, D-27515 Bremerhaven, Germany

⁵Department of Geography, Durham University, South Road, Durham, DH1 3LE, UK

⁶Department of Geology, Colorado College, Colorado Springs, CO 80903, USA

⁷Department of Earth Sciences, University of California, Santa Barbara, CA 93106-9630, USA

Peter.Barrett@vuw.ac.nz

ANTscape is a project of the Antarctic Climate Evolution (ACE) Research Program to develop a series of maps to show changes in Antarctic paleotopography over the last ~100 million years. The reconstructions will provide a base for summarising a range of paleoenvironmental data, and for use as inputs for the next generation of ice sheet-ice shelf models. The present-day bedrock topography from the SCAR BEDMAP project will be used as a starting point for reconstructing past paleotopography, moving to BEDMAP 2 when it becomes available. Six maps, one for each significant climatic regime or shift, are planned: 4, 14, 34, 50, 70 and 92 Ma. Work is well advanced on the map for 34 Ma (Wilson and Luyendyk, 2009, *Geophysical Research Letters*). This is a time that is far enough back for there to be a significantly different topography, but not so far back that reconstruction is seriously unconstrained. It is also of great interest to paleoclimatologists as the largely ice-free landscape on which the first continental ice-sheet formed. Work has also begun on the map for 70 Ma. The topography shown on ANTscape map will be based not only on restoration of Antarctic continental geography by reversing tectonic movements and elevation changes, but also the restoration of sediment eroded from the continent and deposited around and beyond the Antarctic margin. This will require modeling changes to the Antarctic landscape from erosion (Jamieson et al., 2010, *Earth & Planetary Science Letters*) and estimates of sediment volumes through the Circum-Antarctic Stratigraphy and Paleobathymetry Project (CASP). For further information see www.ANTscape.ag

CO₂, TEMPERATURE AND SEA LEVEL OVER THE LAST 65 MILLION YEARS, ICE AGES AND THE FUTURE

P.J. Barrett and D. Zwartz

Antarctic Research Centre, Victoria University of Wellington, P.O. Box 600,
Wellington
Peter.Barrett@vuw.ac.nz

This paper summarises trends in 4 key climate related parameters, atmospheric CO₂, surface temperature, ocean floor temperature and sea level on geological, ice age and human time scales, with model-based projections for the next 300 years. The geological observations come from compilations of geochemical analyses of samples of known age taken from Ocean Drilling cores, whereas data for the last four glacial cycles come from both ice cores and ocean drilling. The geological record shows a much warmer world more than 30 million years ago, with CO₂ levels between 2 and 8 times pre-industrial levels and temperatures 10 to 15°C warmer than today. CO₂ declined gradually but temperature fell sharply 34 million years ago, coincident with the growth of large dynamic ice sheets on Antarctica. CO₂ levels stabilised at around 400 ppm or less around 24 million years ago, whereas the Antarctic ice sheet did not stabilise until ~10 million years later, and the big Northern Hemisphere ice sheets formed just 2.6 million years ago with further cooling, leading to the largest glacial-interglacial sea level swings in Earth's Cenozoic history. This compilation contrasts our clear and consistent documentation of the relationship between CO₂, temperature and sea level during the ice ages with the low CO₂ world of pre-Quaternary times, when climate was 3 to 4°C warmer, and the even more curious situation where global surface temperature fell 4°C at the Eocene-Oligocene boundary but CO₂ took several million more years to decline. It will be useful to understand these basic relationships on a global scale as we consider the consequences of rising greenhouse levels in the coming decades.

ANATOMY OF A PLATE BOUNDARY AT SHALLOW CRUSTAL LEVELS: A COMPOSITE SECTION FROM THE ALPINE FAULT, NEW ZEALAND

Nicolas C. Barth¹, Virginia G. Toy¹, Carolyn J. Boulton², Brett M. Carpenter³

¹Department of Geology, University of Otago, Dunedin, New Zealand

²Department of Geological Sciences, University of Canterbury, Christchurch, New Zealand

³Department of Geosciences, Pennsylvania State University, University Park, PA, USA
nic@geology.co.nz

The Alpine Fault is best known as a moderately SE-dipping dextral reverse plate boundary structure, but along its southernmost 70km onshore, strike-slip-normal motion is indicated by offset of recent surfaces, juxtaposition of sediments, and both brittle and ductile shear sense indicators. At the location of uplift polarity reversal, fault rocks exhumed from both the Pacific and Australian Plates are juxtaposed, offering a remarkably complete cross section of the plate boundary at shallow crustal levels.

The damage zone is asymmetric; on the Australian Plate 160m of quartzose paragneiss-derived mylonites are overprinted by brittle faults and fractures that increase in density towards the principal slip surface (PSS). On the Pacific Plate, only 40m of the 330m section of volcanoclastic-derived mylonites have brittle damage and pervasive hydrothermal alteration.

The active Pacific Plate fault core is composed of ~1m of cataclasite. The active Australian Plate fault core is <1.5m wide and consists of foliated clay gouges with pressure solution textures and stringers of quartz that become less continuous and more sigmoidal toward the PSS. Intact wafers from an Australian Plate gouge, experimentally-sheared in a biaxial configuration under true-triaxial loading at $\sigma_n' = 31\text{MPa}$ and $P_f = 10\text{MPa}$, yielded a friction coefficient, $\mu_{ss} = 0.32$ and displayed velocity strengthening behavior. No significant re-strengthening was observed during hold periods of slide-hold tests.

Well-cemented glacial till (~8000 years old), which caps many outcrops, is a marker that shows that the damage zone is not active in the near-surface, but most of the fault core is. The active near-surface damage zone here is <40m wide and the active fault core is <2.5m wide. Both overprint a much wider, inactive damage zone. The combination of rheologically-weak Australian Plate fault rocks with surface rupture traces indicates distinctly different coseismic and interseismic behaviors along the southern strike-slip-normal segment of the Alpine Fault.

TRENDS IN SANDSTONE COMPOSITION: PROVENANCE ANALYSIS OF THE ANDRILL SMS CORE IN THE ROSS SEA

Kari Bassett¹ and Scott Barnard²

¹ Geological Sciences, University of Canterbury, Prvt Bag 4800, Christchurch

² Gateway Antarctica, University of Canterbury, Prvt Bag 4800, Christchurch
kari.bassett@canterbury.ac.nz

Distinct transitions in sand grain composition in the SMS core record the advance and retreat of local glaciers draining off the Transantarctic Mountains into the Ross Sea basin, volcanic eruptions associated with rifting, and perhaps the collapse of large ice sheets.

Sand grain composition at the top is dominantly primary volcanic recording derivation from a local basaltic vent. Other peaks in volcanic glass content occur between ~170-224m and ~550-660m indicating periods of increased volcanic activity.

Basement-derived grains increase markedly at ~42m. These record derivation from the Granite Harbour Intrusives and Koettlitz Group metasediments, delivered via the local Blue-Koettlitz Glaciers during the height of Plio-Pleistocene glaciations. At ~165m marble drops out, corresponding to the base of the Pliocene deposits and the transition to Miocene glaciations. Below this, marble clasts only occur as isolated peaks which may indicate times of large local glaciers. ~224m depth, ~340m, ~500m and ~600m mark other distinct changes in basement-derived grain compositions and may correspond to advances of local glaciers.

Well rounded quartz grains, some with attached cements, increase abruptly at ~224m, correlating strongly with orthopyroxenes and dolerite lithics. These are derived from Beacon Supergroup sandstones and Ferrar Dolerites. Increases and decreases occur at ~420 m, ~580m, ~640m, ~680m, and ~740m. Beacon/Ferrar grains were locally derived and delivered via the Blue and Koettlitz Glaciers. Therefore changes in concentration probably correspond to alternating glaciations in the Miocene.

The overall loss of Beacon/Ferrar and increasing abundance of marble and other basement-derived grains upsection indicate an unroofing sequence of the Transantarctic Mountains. High concentrations of Beacon/Ferrar derived grains indicate growth of local glaciers alternating with collapse during the Miocene. This echoes changes in basement clast compositions observed by Sandroni et al. (2010) suggesting growth and collapse of the West Antarctic Ice Sheet.

PRELIMINARY SOURCE MODEL FOR DARFIELD EARTHQUAKE FROM GPS AND SATELLITE RADAR OBSERVATIONS

J. Beavan¹, S. Samsonov², M. Motagh³, L. Wallace¹, N. Palmer¹ and S. Ellis¹

¹GNS Science, PO Box 30368, Lower Hutt.

²Dept. of Earth Sciences, University of Western Ontario, London, Ontario, Canada.

³Deutsches GeoForschungsZentrum, 14473 Potsdam, Germany.

j.beavan@gns.cri.nz

We surveyed >80 pre-existing GPS marks 3-10 days after the Darfield earthquake and analysed pre- and post-earthquake ALOS and Envisat satellite radar images. A resurvey of some of the GPS marks two weeks later showed that no major afterslip is occurring. We inverted the GPS displacement data using a model consisting of uniform slip on several rectangular fault planes. The GPS data require at least three faults to be active during the earthquake: the largely right-lateral Greendale Fault and its buried extension for ~6 km beyond the northwest end of the mapped surface rupture; a blind thrust coincident with the earthquake hypocentre; and a blind thrust at the northwest end of the strike-slip fault near Hororata. The main section of the Greendale Fault has an average slip of ~5 m between 0-7 km depth on a plane dipping very steeply to the south (Mw ~6.9). Its NW-trending extension has an average slip of ~3 m on a plane dipping steeply southwest (Mw ~6.6). The northwestern section in particular shows a component of thrusting. The blind thrust near the hypocentre dips steeply southeast, has ~5 m of slip with a significant right-lateral component, and ruptures to within a few km of the surface (Mw ~6.6). The thrust fault near Hororata is less well defined but has ~3 m of slip and ruptures to within 1-2 km of the surface (Mw ~6.1). We use the GPS-derived model to predict the signal observed by ALOS, and find good agreement with its main features. Prior to the conference we hope to have refined the source model by jointly inverting the GPS, ALOS and Envisat data. Acknowledgements to Dave Collett, Josh Thomas, Joe Wright, Kelvin Tait, Kirby MacLeod, Richard Davy and Adam Carrizales for their work during the GPS surveys.

**THE LOCAL SCIENCE RESPONSE TO THE 4 SEPTEMBER, 2010, CANTERBURY
EARTHQUAKE**

S. Beaven¹, J. McIntosh¹, J. Morgan¹, G. Prouting¹, C. Reugg¹, T. Wilson¹, P. Almond², M. Quigley¹, K. Furlong^{1,3}, E. Seville⁴, Z. Whitman^{1,4}, J Stephenson^{1,4}, E Doyle⁵, D Johnston⁵, and others.

¹Department of Geological Sciences, University of Canterbury ²Department of Soil and Landscape, Lincoln University ³Geosciences, Penn State University, USA
⁴Resilient Organisations, University of Canterbury ⁵Joint Centre for Disaster Research, Massey University/GNS Science, Wellington
thomas.wilson@canterbury.ac.nz

The 4 September 2010 Canterbury earthquake is the most damaging natural disaster in New Zealand for over 80 years. The natural hazards research community mobilised in what is arguably one of the largest trans-institutional research responses ever undertaken in New Zealand. It occurred in the context of the recent formation of the natural hazards research platform, designed to reduce competition and increase collaboration amongst researchers. Collaboration and coordination between platform and non-platform affiliated researchers was required at individual and institutional levels, and with policy-makers and practitioners. Immediately after the earthquake a rapid coordination of research priorities were identified and actioned by the responding research community. Physical scientists scrambled to capture the time perishable data. Geological teams had located the surface rupture of the fault within hours and began several weeks of intensive mapping. Engineering teams assisted with building damage assessments. Within days liquefaction mapping teams had been mobilised to record the evidence before it was removed by recovery efforts, and seismologists had deployed an array of temporary seismographs and strong motion sensors. International research teams began arriving within days of the event to undertake reconnaissance assessments and continue to do so.

Societal and economic researchers also collected their data sets after an appropriate grace period, with a strong focus on informing the recovery process. This was more challenging, given the traumatic state of the local community and strong desire not to interfere with operational activities. Local researchers joined several of the recovery groups, initially acting as observers but this transitioned into a research liaison function – with mixed success.

Since the earthquake, research teams have been constantly collecting, analysing and disseminating results as quickly and appropriately as possible to inform information hungry emergency management organisations, the media and public. They have also dealt with incorrect information and hearsay in the media and within socio-political frameworks. Scientists with no formal media training were transformed into overnight ‘earthquake celebrities’.

This paper will present an (incomplete) analyse of some of the successes and challenges for the science community moving forward from this event, particularly with creating timely and useful information to inform response and recovery decision making. It will attempt to explore how modern natural hazards science has become increasingly interdisciplinary and inter-institutional, and the opportunities and difficulties this creates.

**PSEUDO-3D SHEAR VELOCITY STRUCTURE OF THE CENTRAL NORTH ISLAND
DETERMINED FROM AMBIENT NOISE ANALYSIS OF TEMPORARY AND PERMANENT
SEISMOGRAPH DATA**

Y. Behr¹, J. Townend¹, S. Bannister² & M.K. Savage¹

¹SGEES, Victoria University of Wellington, PO Box 600, Wellington
²GNS Science, PO Box 30-368, Lower Hutt
yannik.behr@vuw.ac.nz

The use of ambient seismic noise as a pervasive energy source is now an established strand of seismology. It requires relatively short instrument deployment times and no artificial sources, thereby providing an economical and low-impact means of gaining new insights into crustal and upper mantle structure. The central North Island and the Taupo Volcanic Zone in particular have been the focus of many studies utilising complementary geophysical methods. Information on the shear velocity structure derived from short-period surface wave analysis fills a gap in geophysical information from previous active- and passive-source studies.

Here we reprocess three-component data from four temporary seismic arrays that were deployed in the central North Island and data from permanent seismic stations, using ambient noise correlation techniques. As the temporary deployments involved different types of broadband instruments and the necessary instrument response information was in some cases incomplete or ambiguous, we use teleseismic events and the noise-correlation techniques suggested by Sens-Schoenfelder et al. [*GJI*, 2008] to determine the correct instrument responses and timing errors. We then calculate Rayleigh and Love wave dispersion curves from ambient noise correlation and invert the dispersion curves for a pseudo-3D shear velocity model of the crust.

Low shear velocities (<3.1 km/s) in the upper crust above depths of ~15–20 km beneath the central TVZ coincide with presumed source regions for the rhyolitic volcanism in the Taupo Volcanic Zone. The comparison with results from active and passive source studies [Reyners et al., *GJI*, 2006; Stern and Benson, *JGR*, submitted; Harrison and White, *GJI*, 2006] as well as magnetotelluric studies [Heise et al., *GRL*, 2007, 2010] reveals a number of consistent features and confirms that shear velocity measurements obtained by ambient noise analysis complement other geophysical observations and provide new insight into lithospheric structure.

DEEP GEOTHERMAL EXPLORATION WITH AN ARRAY OF MAGNETOTELLURIC DATA

**E.A. Bertrand¹, T.G. Caldwell¹, G.J. Hill¹, E. Wallin¹, S.L. Bennie¹, N. Cozens¹,
S. Onacha², G. Ryan², C. Walter², A. Zaino² & R. Malin²**

¹GNS Science, PO Box 30368, Lower Hutt 5040, New Zealand.

²IESE, University of Auckland, Private Bag 92019, Auckland 1142, New Zealand.
t.bertrand@gns.cri.nz

The Taupo Volcanic Zone (TVZ) in the central North Island of New Zealand is marked by intense silicic volcanism, an active continental rift, and an extremely high natural heat output. In the upper crust of the TVZ, this heat flux is transported to the surface via convection in 23 high-temperature geothermal systems. Over the past 50 years, several of these geothermal systems have been explored down to depths of 2-3 km with temperatures reaching up to 330°C. Geothermal power plants currently provide ~15% of New Zealand's electricity supply. However, to maintain, or to increase this level of geothermal energy production in the long term, future exploration to depths >3 km will be required where temperatures may approach 400°C.

To reduce the risks associated with future deep geothermal drilling in the TVZ, a research project consisting of structural geology, experimental geochemistry, passive seismic and magnetotelluric (MT) measurements has been initiated. The MT component of this project includes the acquisition of ~220 broadband MT measurements spaced ~2 km apart in a rectangular array. The survey area is located in the south-eastern part of the TVZ and extends across the central rift axis to the rift margin. The goal of these MT measurements is to identify structures present within the basement rocks at depths between 3 and 7 km that may be related to deep geothermal resources. It is hoped that these MT data will provide an improved understanding of the geothermal resource potential beneath the TVZ, and will encourage future exploration beyond the present maximum drilled depth (~3 km). Preliminary 3-D resistivity models of the MT soundings that have been collected to date will be presented.

RECONNAISSANCE OF AN EARTHQUAKE INDUCED LANDSLIDE FROM THE CANTERBURY QUAKE

**E. L. Bilderback¹, T. Stahl¹, S. McColl¹, C.I. Massey², M. Quigley¹, P. Villamor²,
D. Nobes¹, & D. Noble¹**

¹Dept. of Geological Sciences, University of Canterbury, Christchurch.

²GNS Science, Lower Hutt, New Zealand.
elb48@uclive.ac.nz

The ~M7.1 earthquake that struck Canterbury in September 2010 generated few landslides due in part to the epicentral distance to steep hillslopes and the competent rock of Banks Peninsula. Most of the mass movements recorded were minor rock fall, lateral spreading, or failure of saturated fill. In contrast, surface cracks in the Harper Hills, Northwest of Hororata, seem to indicate coseismic triggering of a large deep-seated landslide, associated with strong ground shaking (PGA close to 0.8 g). Here we present the results of field and geophysical reconnaissance of this feature.

The morphology of the Harper Hills along the dip slope is > 100 m scale rolling hill country with slope-parallel drainages and numerous small depressions and swales that have been dissected by streams. NE striking, SE dipping beds comprised of Tertiary transgressive-regressive packages are interrupted by at least two distinct periods of volcanism, the younger of which provides the tuffaceous parent material for two seams of nonswelling, beidellite and montmorillonite bentonite (Carlson 1971). Bentonite exhibiting numerous slickensides is exposed in a quarry close to the crest of the hills.

Land owners first noticed ground cracks on the 5th of September and assumed that they occurred coevally with the main earthquake. A stock pond dissected by one of the cracks drained after the initial earthquake, refilled and then drained again in a large aftershock. The approximately linear cracks have been traced intermittently for almost four kilometres below the crest of the Harper Hills dip slope. All of the cracks show a sense of extension (<0.5 m) with some vertical displacement. Stakes for monitoring additional movement across the cracks were installed on the 10th of September and have shown no further down slope extension. Several active shallow landslides on the Harper Hills showed no evidence for reactivation by the earthquake. We are continuing to investigate the dynamic failure mechanism and why the earthquake triggered apparently deep-seated failures while other slopes on shallower pre-existing slide planes at residual strength, remained stable.

EFFECTS OF FLUIDS ON THE DEFORMATIONAL BEHAVIOUR OF THE ALPINE FAULT: A MULTI DISCIPLINARY APPROACH

M.A. Billia¹, V.G. Toy¹, P. Upton²

¹Dept. of Geology, University of Otago, PO Box 56, Dunedin.

²GNS Science, Private Bag 1930, Dunedin.

marco.billia@alumni.ethz.ch

Major crustal fault zones and smaller faults in general need to be weak with respect to the surrounding rock to allow strain localization and subsequent focussing of deformation within them. Experimental lab data indicates several ways that fluids influence the deformational behaviour of crystalline rocks; for example, fluids significantly reduce flow stresses in dislocation creep regimes¹, water may affect the re-crystallized grain size², which can modify the ductile deformation mechanism, and the presence of CO₂-rich fluids causes strengthening or weakening in dislocation creep experiments depending on fO₂ of the host rock³.

New Zealand's Alpine Fault zone and its hangingwall are characterised by geophysical properties that could result from the presence of fluids. For example, low seismic velocities are apparent in the hangingwall in seismic transects⁴. Furthermore, high magnetotelluric conductivities are measured down-dip and along strike of the fault zone^{5,6}. The latter could either be interpreted to indicate saline fluids are present in a dynamic and interlinked fracture network within the shear zone, or result from the presence of dispersed graphite⁷.

We will present results from the initial stages of a study aimed at quantifying fluid contents in the mylonitic sequence based on FT-IR measurements, characterising and quantifying microstructures of cohesive fault rocks by SEM, EBSD and CIP and constructing a P-T-D framework for Alpine Fault mylonites by means of geothermobarometry and computational thermodynamics focussing on their progressive exhumation from the lower crust. The latter allows us to precisely examine how presence or absence of fluids affects the stable mineral assemblage. We also focus on the role of solution-precipitation creep, which may be triggered by the presence of fluid- or graphite at mid-crustal levels.

First indications point towards fluid-rich conditions during mylonitization including significant intracrystalline H₂O-contents and evidence of grain boundary fluids.

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NEW INSIGHTS INTO THE WAIRAKEI-TAUHARA GEOTHERMAL SYSTEM FROM RECENT DEEP DRILLING RESULTS

P. F. Bixley & K. P. McLean

Contact Energy Ltd, Wairakei Power Station, PB 2001, Taupo 3352.

paul.bixley@contactenergy.co.nz

During the first 50 years of development at Wairakei only two deep wells were drilled: WK121 (2255 m) in 1968 and WK301 (1976 m) in 1984. Otherwise the bulk of the production wells had been drilled to around 600 m with some wells to 1300m. Over the last four years 10 deep wells (>2000 m) have been drilled into the Wairakei-Tauhara system. The results from these wells confirm the conceptual model of two separate upflows: in the western part of Wairakei where a 255 °C upflow feeds the Wairakei system and in the eastern part of Tauhara where a deep recharge of >300°C has been identified. Together with the reservoir pressure response to reinjection of separated geothermal water, the deep wells have provided new insights into the nature of the hydrological connection between the two fields.

SEDIMENTARY PETROGRAPHY OF WAITEMATA GROUP SEDIMENTS: CONTROLS ON THEIR ENGINEERING GEOLOGICAL PROPERTIES

P.M.Black

Geology, School of Environment, University of Auckland.
pm.black@auckland.ac.nz

Early Miocene Waitemata Group sediments underlie most of the greater Auckland urban area. They are readily excavated, and generally stand up well in steeply cut slopes. In engineering geological terms they are soft rocks, typically with uniaxial compressive strengths of c. 5 MPa. East Coast Bays Formation (ECBF) and Pakiri Formation, both turbidite sandstone and laminated mudstones, form an older central core of the Waitemata Basin. Lithic material in the ECBF is dominantly mudstone; to the north ECBF transitions with increasing volcanic lithic content into Pakiri Formation. Proximal volcanic sandstone sequences outcrop along the West Coast adjacent to the Manukau and Kaipara volcanic centres.

Diagenetic minerals in unweathered sediments are zeolites (dominantly clinoptilolite with minor analcime). Volcaniclastic members and occasional tuffaceous horizons also have chabazite and erionite. Smectite is the dominant clay in sediment matrices and mudstone clasts. Illite also occurs in the volcaniclastic sediments. Estimated temperatures of diagenesis are 60 - 100°C. XRD and SEM studies show edge-face clay plate attraction and zeolite cement provide the strength of the sediments. The sediments have a weathering profile up to 15m thick in which smectite is progressively transformed to kaolin minerals.

ECBF sandstones may have exceptionally high total smectite contents (up to 40 %) because their lithic fragments are dominantly mudstone. When subject to aggressive mechanical breakdown ECBF sandstones have the potential to destructure thus combining the clay content of matrix and clasts and produce sticky spoil problems. The deeper the excavation in the weathering profile the more likely it will be to experience sticky spoil problems in ECBF.

UNDERSTANDING SHALLOW GROUNDWATER RECHARGE IN CHRISTCHURCH, NEW ZEALAND THROUGH COMBINED PHYSICAL AND CHEMICAL DATA ANALYSIS

J.M. Blackstock¹, T. Horton¹, & P. Zavar-Reza¹

¹Geological Sciences Dept., University of Canterbury, Private Bag 4800, Christchurch

Determining sustainable water resource utilization rates is an important problem faced by regulatory agencies all around the world. Land-use intensification, including significant increases in dairying in New Zealand, has placed a priority on developing water resource management practices. One of the key parameters in determining accurate water budgeting schemes is the rate of water resource replenishment, or 'recharge' in groundwater systems. Fundamental questions regarding recharge include the source, its spatial distribution, and rate of recharge. Answers to these questions can be gained through combining physical and chemical hydrogeological observations, including stable isotopic compositions.

Basic chemical data, including potential tracers such as $\delta^{18}\text{O}$ and δD , are generally absent at the regional scale. Here we present the first compilation of $\delta^{18}\text{O}$ and δD values from individual precipitation events, local surface waters, depression springs, and groundwaters from the greater-Christchurch area. A variety of analytical methods were used in an effort to evaluate the potential use of water resource stable isotopic compositions as tracers of surface-groundwater interaction in the local hydrologic cycle.

Our analysis produced several important findings: 1) Hybrid Single Particle Lagrangian Intergrated Trajectory (HYSPLIT) analysis does not yield a consistent pattern relating isotopic composition to air parcel trajectory. 2) shallow groundwater and depression spring isotopic compositions match high-altitude derived braided river waters, but not local precipitation. However, further research is needed to better constrain long-term average $\delta^{18}\text{O}$ and δD values for precipitation. 3) long-term trends in piezometric surface elevations reflect changes in river base flow conditions; 4) short-term fluctuations, in piezometric surface elevations, correspond with significant precipitation events. In combination, these results present a compelling case for shallow groundwater recharge by surface water channel leakage in this portion of the Canterbury Plains, demonstrating the potential application of combined physical and chemical hydrologic data analysis to informing water resource management and decision-making practices.

GEOLOGY FOR BIOLOGY: PLIO-PLEISTOCENE PALEOGEOGRAPHY OF NEW ZEALAND'S NORTH ISLAND – SOUTH ISLAND JUNCTURE

Kyle J. Bland¹, Steve A. Trewick², Dominic P. Strogen¹, & Andy Nicol¹

¹GNS Science, PO Box 30368, Lower Hutt

²Institute of Natural Resources, Massey Univ., Private Bag 11-222, Palmerston Nth
k.bland@gns.cri.nz

Biogeography seeks to explain the distribution of biological diversity in space and time. Contrasting regional endemism and diversity highlight central New Zealand as an area of interest to biogeographers and evolutionists. This area, which extends from Taupo to northern South Island, is also of interest to geologists as it encompasses a zone of intense tectonic deformation related to subduction of the Pacific Plate and the change of plate motion behaviour from subduction to the Alpine Fault. Cook Strait, a marine breach across the trend of New Zealand's extensive axial ranges, is a geologically young feature, and the shape and position of what we now consider to be "North" and "South" islands has changed significantly during the past 4 m.y.. These changes have likely influenced the biogeography of region.

A series of new paleogeographic reconstructions, produced using updated geological mapping and other recently compiled data sources, depict the latest Neogene (c. 4 to 0 Ma) development of central New Zealand. The maps illustrate the general type of inferred terrestrial topography, in particular the distribution of mountains >1000 m. The maps show that much of southern North Island was submerged until c. 1.5 Ma. Until the relatively recent formation of Cook Strait during the past 0.5 m.y., the Wellington area was geographically part of northern South Island. The Kaimanawa Range area was probably terrestrial from latest Miocene time, with mountainous topography developing during the Early-Late Pliocene and Late Pliocene in the Kaimanawa and Kaweka ranges, respectively. By contrast, the Ruahine-Tararua ranges, which are the dominant topographic features in southern North Island, are relatively young, having only formed since c. 1 Ma.

The implications for the late Neogene biogeography of central New Zealand are considerable in terms of habitat availability for terrestrial species and opportunities for range shifting of both terrestrial and coastal organisms.

THE COMPLETION OF THE GEONET HIKURANGI MARGIN MONITORING NETWORK: WHAT COMES NEXT?

Lara Bland

GNS Science, PO Box 30368, Lower Hutt 5040, New Zealand

l.bland@gns.cri.nz

As the GeoNet Project enters its tenth year of operation, the expansion of instrumentation along the Hikurangi Margin is nearing completion. The Hikurangi Margin Network (HiMNet) is made up of short period seismometer and continuous Global Positioning System (cGPS) stations designed to measure seismicity and deformation associated with the subduction of the Pacific Plate under the Australian Plate, off the east coast of the North Island. The stations are positioned from East Cape to the Marlborough Sounds at approximately 20-30km spacing, and extend inland from the east coast of the North Island for between 80 and 120km. The network is scheduled for completion by July 2011, with a targeted total of 53 regional seismic stations and 80 cGPS stations.

With the HiMNet completed, the focus of GeoNet expansion will shift to strong motion instrumentation, adding 120 new stations to those already in place across New Zealand. In 2010-2011, thirty one new strong motion sites and nine upgrades are planned for the Wellington, Marlborough, West Coast and Gisborne regions. By 2014 a further 80 strong motion accelerometer sites will be added, enhancing the network coverage of the Marlborough Fault System and Alpine Fault. Additional broadband, short period, and GPS stations are also planned for the upper South Island as far south as Oxford, in Canterbury.

MICROSEISMICITY IN THE CENTRAL SOUTHERN ALPS

Carolin Boese, Tim Stern, Euan Smith, John Townend, Mark Henderson

SGEES, Victoria University of Wellington, PO Box 600, Wellington

boesecaro@myvuw.ac.nz

The Southern Alps Microearthquake Borehole Array (SAMBA) of 11 short-period seismometers has now been recording earthquakes in the central section of the Southern Alps for 2 years. The network has been expanded to the South by one additional site and extends now from the Whataroa to the Karangarua River. Approximately 1300 earthquakes of magnitude $-0.5 < M_L < 3$ have been analysed regarding their absolute and relative locations, magnitudes and focal mechanisms. This is the longest microseismicity study in this region to date.

The majority of the earthquakes occur at depths shallower than 10 km in a zone 8 to 25 km to the southeast of the surface trace of the Alpine Fault. Mapped secondary faults are dense in this region, but no particular fault plane can be identified from the locations. Many events are highly clustered in time and space, exhibit similar waveforms and focal mechanisms. The catalogue of recorded events is complete to a cut-off magnitude of approximately $M_L=1$. Our observations reinforce previous results indicating very low levels of seismicity northeast of the Whataroa River, a possible site of future deep drilling.

Earthquakes triggered by the $M_w=7.8$ Dusky Sound earthquake of 15 July 2009 lasted for 5 days before the rate of seismicity returned to its previous level. This sequence has been investigated in more detail and consists of events with predominantly oblique strike-slip focal mechanisms.

SUSTAINABLE FUTURES & LOW ENTHALPY GEOTHERMAL RESOURCES

Diane Bradshaw¹, Darryn Hitchcock²

¹GNS Science, PO Box 30368 Lower Hutt 5040, New Zealand

²GNS Science, Wairakei Research Centre, Private Bag 2000, Taupo, 3352, New Zealand

Keywords: Low enthalpy, geothermal resources, Ngāti Porou, Te Puia Springs, Whakarewarewa Thermal Village, Rotorua, rural Māori communities, Māori traditional knowledge, direct utilization.

New Zealand Energy Strategy to 2050 seeks to increase the nation's use of renewable energy. As part of the strategy there is potential to increase the use of lower temperature, low enthalpy geothermal resources. (Carey B. 2010).

For decades geothermal waters have been used for a wide range of domestic, agricultural and industrial applications that involve the utilisation of geothermal heat, known as *direct use*. More than 90% of the annual energy from direct (heat) use(s) in New Zealand is derived from wastewater from geothermal power stations (cascade); and little is made use of other sources such as hot spring systems. (White, B. 2006).

Nowadays industrial process heating, agricultural drying and domestic space heating account for a large proportion of the energy from direct use of geothermal energy, but bathing is still the most common use for low temperature geothermal waters. Successful uptake of geothermal technologies will result in increased utilisation of New Zealand's low enthalpy resources, with benefits including increased energy production security and lower environmental impacts. Many of New Zealand's geothermal resources lie under land owned by Māori.

A number of significant geothermal surface features and place names provide an indication of the whakapapa (origins) of many dominant features which have existed in these areas for many centuries. These features are intertwined with the traditional values of many Iwi/Māori groups.

This paper examines some of the research findings in order to establish the social understanding that exists with regard to low temperature energy use systems, seeking to identify the level of understanding of these systems by Māori. Cultural factors can influence the acceptance and use of low temperature geothermal resources in New Zealand. A specific focus of this discussion will examine traditional knowledge and perceptions for whom geothermal resources may be of cultural and spiritual significance or who may be interested in building capabilities for new technologies from an international perspective.

THE DYNAMICS OF PYROCLASTIC DENSITY CURRENTS ON MARS

B. Brand

University of Washington, Box 351310, Seattle, WA 98195, USA
bbrand@u.washington.edu

The products of explosive volcanism have long been observed on the surface of Mars, and their corresponding dynamics, associated with phenomenon such as magma fragmentation and eruption columns under Martian conditions, have been modeled with success (e.g., Wilson and Head, 1994). However, the dynamics of pyroclastic density currents (PDCs) under Martian conditions is still poorly constrained. Our increasing capability to image the surface at high resolution, both from orbit and from rovers, presents an opportunity for more rigorous deposit observations and descriptions (e.g., Highland Patera and Home Plate, Gusev Crater), motivating the need for a better understanding of these processes. We have developed a quantitative, axi-symmetric model for flow of and sedimentation from a steady-state, vertically uniform dilute density current for application to PDCs on Earth and Mars. The conservation of mass, momentum, and energy are solved simultaneously, and include the effects of atmospheric entrainment, particle sedimentation, basal friction, temperature changes, and variations in current thickness and density. For a given set of identical initial conditions, our models show that PDCs on Mars will out distance those on Earth by approximately 33%, primarily due to slower sedimentation rates. In addition, we find that when sedimentation of particles and entrainment of atmosphere are included, the runout distance becomes six times shorter than previous model results suggest. Additionally, we calculate the Rouse number and Brunt-Väisälä frequency to estimate the wavelength of internal gravity waves in the density stratified currents, which are thought to be the primary control on deposit bedform wavelength and amplitude (Valentine, 1987). The model predicts realistic wavelengths on Earth (dunes from 20-200 m), whereas longer wavelengths are predicted on Mars. This difference likely reflects the fact that lower particle settling velocities on Mars result in density stratification over a greater vertical extent, and thus longer-wavelength standing waves.

ENGINEERING GEOLOGICAL MAPPING OF A LARGE STRATO-VOLCANO SLOPE FAILURE IN NORTHERN BRITISH COLUMBIA, CANADA

M.-A. Brideau¹ & D. Stead²

¹School of Environment, University of Auckland, Auckland.

²Department of Earth Sciences, Simon Fraser University, Burnaby, Canada.
m.brideau@auckland.ac.nz

Ruby Mountain is a Quaternary strato-volcano located near Atlin in northern British Columbia, Canada. Regional surficial geology mapping by previous workers identified the initiation scar and deposit of a large (~60 Mm³) prehistoric landslide on the eastern flank of the volcano. The failed rock mass descended 700m vertically between the top of the initiation zone and the toe of the deposit. The geomorphic expression of the boulder-rich portion of the deposit suggests that the landslide travelled horizontally at least 3.3km. In the sections exposed in Ruby Creek, the landslide deposit overlies glacial till. Despite the current vegetation cover (grass and shrub), conical mounds were observed in the landslide deposit. The observed hummocky morphology of the failure debris has been reported in association with the failure of volcanic edifices at several locations around the world and also locally in New Zealand (e.g. west side of Mount Taranaki).

Detailed engineering geological mapping at 25 field stations within the initiation zone included recording the orientation and surface characteristics of 500 discontinuities. Five discontinuity sets were identified within the heavily fractured rock mass. Assuming a 30° friction angle, kinematic analysis suggested that planar and wedge sliding were feasible failure mechanisms. A limit equilibrium surface wedge combination analysis indicated that only 2% of all valid wedges created from the field discontinuity measurement were unstable. Based on point load testing results and field estimates of the rock mass quality using the Geological Strength Index (GSI), three geotechnical units were identified in the headscarp area: pyroclastic flow (I₅₀: 0.7; GSI: 40-50), scoriaceous basalt flow (I₅₀: 2.5; GSI: 50-60) and porphyritic basalt flow (I₅₀: 10.9; GSI: 50-60). Limit equilibrium analyses (composite-circular method of slices) assuming an isotropic rock mass strength based on the field observations and laboratory results suggested stable slope conditions; the introduction of a strength anisotropy approximating the bedding orientation produced calculated factors of safety between 0.9-1.1.

CONTROLS ON VOLCANISM IN THE SOUTH AUCKLAND VOLCANIC FIELD

R.M. Briggs¹, A. Pittari¹ & M.D. Rosenberg²

¹Dept. of Earth & Ocean Sciences, University of Waikato, Hamilton

²GNS Science, Wairakei Research Centre, Taupo
r.briggs@waikato.ac.nz

In the South Auckland volcanic field (SAVF), decompression melting of sub-continental lithospheric mantle due to mild extension produced basaltic magmas that ascended largely unmodified through the crust. The localisation of vents at the surface was strongly controlled by faulting in the upper crust, with at least 35 of the 91 volcanoes of the SAVF aligned along known faults, particularly the Drury and Waikato faults. The nature of the eruption style, whether magmatic or phreatomagmatic, was determined by the local hydrology and geology of the shallow basement rocks. In the area north of the Waikato Fault and west of the Drury Fault, the Pliocene Kaawa Formation (up to 250 m thick) comprises shallow marine and estuarine sands, and has the highest aquifer transmissivity of any of the basement formations underlying the SAVF. This is shown by the large number of tuff-rings (29) in this area, compared with the uplifted Hunua block (east of the Drury Fault) of Mesozoic indurated metagreywackes with very low transmissivity where there are only effusive centres. The Mercer Sandstone of the Waitemata Group and Quaternary alluvial deposits are other likely aquifers. K-Ar age data from 43 centres indicate that there are no age patterns, although there are clusters of younger vents in the central parts of the field and older ones in the periphery, but this is possibly related to burial of older vents in the centre. This is suggested by drillholes near Pukekohe that have encountered a succession of lava flows intercalated with Quaternary deposits. Scatter plots of various geochemical parameters, e.g. distribution of contrasting basalt types, also show no spatial patterns in composition across the field, so the rapid generation of small volumes of basaltic magmas in the upper mantle appears to be sporadic and localised.

THM16 BACK-FILL OPERATION

K. Brockbank, D. Cammell & K. McLean

Contact Energy, Wairakei Power Station, Private Bag 2001, Taupo.
kerin.brockbank@contactenergy.co.nz

During 2008-2009 Contact drilled 14 cored wells to investigate the causes of subsidence in the Tauhara field. One of these wells, THM16 is located in the centre of the Crown Road Subsidence Bowl where subsidence rates of up to 60 mm/year have been observed. After completion THM16 was intended to be used as a Waiora formation pressure monitor because of its location in the subsidence bowl.

The well was drilled to 800 m with the 4.5" production casing shoe at 424 m and a 3.5" perforated liner. Two very permeable feed zones were identified at 440 m and 770 m both in the Waiora formation.

The heat-up temperatures and spinner profiles showed an interzonal flow of ~30 t/h at 200 °C was entering the well at 440 m and exiting the well at 770 m. In order for this well to be used as a pressure monitor the interzonal flow needed to be stopped. It was decided that blocking off the 770 m feed zone and leaving the 440m zone available for pressure monitoring would be the best solution. Several options to achieve this were considered and it was decided that a top down backfill would be a cost effective alternative that could be trialled prior to the use of a drilling rig to plug the bottom section of the well. The top down backfill successfully achieved the objective by utilising fine sand (crusher dust) and bentonite pellets to plug the wellbore between the two feed zones.

The well was back-filled in two stages: In the first stage the well was plugged back to 646 m, but spinner profiles showed the interzonal flow had not been completely stopped, and additional feed zones were also identified at this time. During the second stage the well was back-filled to 541 m and repeat spinner profiles showed the interzonal flow had been stopped.

THM16 now has a capillary tubing system installed with continuous downhole pressure monitoring equipment. A success!

WAIRAKEI - TAUHARA GEOTHERMAL SUBSIDENCE: RECENT INVESTIGATIONS

C. Bromley¹, T. Glynn-Morris², S. Currie³ & M. Rosenberg¹

¹GNS Science, Bag 2000, Wairakei, Taupo.

²Contact Energy, Wairakei Power Station, Bag 2001, Taupo.

³Energy Surveys, Box 1905, Taupo.
c.bromley@gns.cri.nz

Over the past two years, Contact Energy has funded a comprehensive research programme investigating subsidence anomalies located within the Wairakei-Tauhara geothermal system, focussing on temporal and spatial changes, geological and geotechnical rock properties, and underlying mechanisms. This has involved collaboration between specialist teams of geoscientists, engineers, surveyors and drillers. About 4 km of continuous core from 13 boreholes was logged and preserved for geotechnical analysis including compressibility measurements. Tests also included petrology (XRD, smectite abundance, SEM) and down-hole reservoir measurements (temperature, pressure, permeability). Modelling (constrained by measured rock properties and interpolated pressure changes) was undertaken to simulate historical trends and to predict future subsidence rates for each anomaly. This paper summarizes the results of these investigations, with a particular focus on the localised Wairakei subsidence anomaly (15m total; rate now levelling off), which has been the object of much speculation regarding its cause.

As a result of the research programme, there is a much improved understanding of the processes involved and the specific causes for location, amplitude and timing of these subsidence anomalies; consequently, uncertainties regarding future effects have significantly reduced. The underlying cause of Wairakei-Tauhara subsidence is pressure decline in steam zones. Non-linear effects, such as yielding, stiffening and inelastic rebound (accompanying pressure increase) affect the history of rate changes, as does slow pressure diffusion into low permeability clay layers. Measured compressibility values vary widely within and between formations due to heterogeneous lithology and alteration of the volcano-sedimentary sequence. In the centre of the Wairakei bowl, compressibility of Huka Falls Formation sediments and upper Waiora Formation breccia at 75m to 330m depth ranges from 0.01 to 0.14 MPa⁻¹. Intense hydrothermal clay alteration is a distinguishing characteristic of the weaker material in these formations. A localised thin zone of organic material at 30-45m depth has undergone thermogenic decay, contributing to the total subsidence.

HIGH RESOLUTION SEISMIC IMAGING OF AN ACTIVE OFFSHORE COAST-PARALLEL FAULT SYSTEM ON THE SHALLOW OTAGO CONTINENTAL SHELF, SOUTH ISLAND, NEW ZEALAND

C.D. Bruce¹ & A.R. Gorman¹

¹Dept. of Geology, University of Otago, PO Box 56, Dunedin.
bruca012@student.otago.ac.nz

The offshore extent of the active Akatore Fault, a NE- SW trending reverse fault that runs along the coast SW of Dunedin is poorly constrained. The Akatore Fault is associated with several possible offshore coast-parallel faults based on shallow controlled-source seismic data. Several earthquakes, including those of 1974 and 1989, are attributed these faults.

Single-channel electro-acoustic 'Boomer' and Chirp seismic reflection data were collected along with side scan sonar along 89 lines. 484 km of 'Boomer' data were collected over ~550 km²; only 293 km of Chirp and side scan lines were collected due to weather conditions. The majority of lines were collected along NW-SE azimuths, running from just outside the surf zone (<10 m water depth) to a maximum of 28 km offshore (~75 m water depth). Survey lines were approximately 250 m apart near shore and up to 5 km apart offshore. One 'Boomer' line ties the 1978 Takapu-1A well.

Most lines image distinct east-dipping reflections that correlate to the nearby Cretaceous-Tertiary sequence. 'Boomer' subsurface penetration is limited primarily by the presence of multiple reflections. Primary reflections were recorded from subsurface depths of up to 100 m. In several areas, internally reflective basement schist was interpreted.

Several significant structures were imaged within the survey area: (1) the Akatore Fault, (2) the Green Island Fault, and (3) the Takapu Anticline. The Akatore Fault was imaged very near shore in the southern portion of the survey, and a minimum displacement of 55 m was calculated. Offset on the Green Island Fault, a large high-angle reverse fault, that may be a step-over from the Akatore Fault was relatively well constrained to ~200 m (east side up). High-resolution imaging of the Takapu Anticline suggests that the Takapu Fault does not reach within ~80 m of the seafloor.

BIG BORE WELL DRILLING IN NEW ZEALAND – A CASE STUDY

J. Bush¹ & C. Siega¹

¹Mighty River Power Ltd, Rotorua, New Zealand
Christine.Siega@mightyriver.co.nz

A typical standard geothermal well in New Zealand is a 9-5/8" cemented production or injection casing completed with a 7" perforated liner in an 8.5" hole. In 2006, one geothermal operator began looking at big bore completions as a way to improve the cost per megawatt of its drilling operations by reducing the number of wells required per field. After an initial review, it was concluded that a big bore well completed with 13-3/8" cemented casing and 9-5/8" perforated casing could increase the productivity or injectivity of wells by 66% for a cost increase of 17% and minimal additional risk. Starting in 2007, big bores were included in the drilling program in the Mokai, Kawerau and Rotokawa geothermal fields.

Nine standard wells and twelve big bore wells, both production and injection, were drilled from 2007 to the beginning of 2009. The results of the drilling and testing program show that big bore wells can successfully reduce drilling costs as well as the number of wells required, but are dependent on the characteristics of the field.

WHY THE DARFIELD EARTHQUAKE WAS NOT A SURPRISE

Jocelyn Campbell¹ & Jarg Pettinga²

^{1,2}Dept. Of Geological Sciences, University of Canterbury, PB4800, Chch.
jocelyn.campbell@canterbury.ac.nz

Media sources have stated that an earthquake of M 7.1 magnitude on an unknown fault close to Christchurch had not been predictable. Certainly, the east-west striking Greendale Fault rupture 5 km south of the 4th September epicentre had no known surface expression, but active deformation and the convergence of emergent structures into this location are well known. Paleoseismic data show this is at least the fourth event of this size to have occurred at ~300 year intervals within a 60 km radius of the city and that topographically expressed emergent structures with late Holocene displacements are within 25 km. Many more faults record multiple, but individually undated, post-glacial events with the majority of rural townships located on them. After a hiatus, the tempo of activity along the range front may have accelerated in the last 2kyr.

Plate boundary deformation creates a southeasterly propagating, repetitive structural pattern produced by the migration of the east-northeast strike-slip Marlborough Fault System intersecting step-wise evolution of northeast trending thrusts. Regularly this pattern is segmented by east-west faults apparently inherited from reactivated Cretaceous normal faults. The foothill structures provide insight into the evolution of blind structures now propagating under the eastern Canterbury Plains, where thrust and strike-slip fault activity are closely linked. Widely spaced, northwest-striking fault zones transect the whole orogen and may partition stress transfer across it.

East-west, well-expressed strike-slip faults thus form transfer structures truncating thrust segments where early stages of emergence are dominated by anticlinal growth, blind or partially buried, primary thrusts and backthrusts. Transfer faults are therefore tape recorders for episodes of uplift and shortening with variable H/V ratios and displacements. Intraseismic and precursor fold growth appears to be significant, affecting river bedforms. The Greendale fault and aftershock pattern are compatible with this style and the location of known growing anticlines.

GEOLOGICAL CONSTRAINTS RELEVANT TO THE ZEALANDIAN DROWNING HYPOTHESIS

H.J. Campbell

GNS Science, 1 Fairway Drive, Avalon, PO Box 30-368, Lower Hutt 5040
h.campbell@gns.cri.nz

The suggestion that Zealandia may have been totally submerged c. 23 Ma in early Miocene time was published by Chuck Landis and others in early 2008 (*Geological Magazine* 145: 173-195). This idea was the product of a collaborative project involving geologists and biologists. However, it was substantially based on geological considerations and importantly recognition of the Waipounamu Erosion Surface and its significance. The paper generated considerable interest and has provided impetus to new research, especially in the biological world. The idea that New Zealand is a remnant of a continent (Zealandia) has created a new paradigm for ecologists and evolutionary biologists.

The primary biological effort has been the application of molecular biology. What is interesting is that the results tend to support the geological suggestion. They indicate an overwhelming origin of the New Zealand native biota from Australia, not Gondwanaland; the timing of genetic separation is less than 23 m.y. for all groups studied (selected plant, animal and insect groups).

On the other hand, paleontological investigations of Miocene fossil biota from freshwater sediments in Otago tend to suggest otherwise. They appear to demand a continuous presence of land. Or do they? A lot hangs on paleobiology considerations: the apparent diversity and state of evolution of the fossil biota. The age of the sediments in question is also problematic.

What we can be certain of is that by earliest Miocene time there was a very substantial reduction in land area of Zealandia. There may well have been islands but geological evidence for long-lived islands is still tenuous or non-existent. At best we surmise that there may have been ephemeral short-lived islands in the region. Perhaps collectively, such islands may have created the same effect as a long-lived island. There is much uncertainty.

How can we move forwards? One line of enquiry that has real promise is provenance research: investigations of the source of clastic sediments in Oligocene-Miocene sedimentary sequences.

2D AND 3D GPR IMAGING OF THE ALPINE FAULT STEP-OVER ZONE NEAR INCHBONNIE, NEW ZEALAND

S. Carpentier¹, S. Boschetti¹, R. Langridge², A. Green¹, J. Doetsch¹, A. Abächerli¹, A. Kaiser², H. Horstmeyer¹, F. Hurter¹, M. Finnemore³

¹Institute of Geophysics, ETH Zurich, Zurich, Switzerland

²GNS Science, Lower Hutt

³Department of Geological Sciences, University of Canterbury, Christchurch
carpentier@aug.ig.erdw.ethz.ch

A recent geomorphological study at the Alpine Fault (AF) step-over zone near Inchbonnie has led to revised slip-rate estimates for the Alpine Fault at this location. Dextral strike-slip rates and dip-slip rates on the AF have been updated to 13.6 ± 1.8 and 3.4 ± 0.6 mm/yr respectively. These values are still consistent with a northward decrease in Alpine Fault slip rate of approximately 50% across the intersection with the Hope Fault (HF), with significant implications for seismic hazard. Although the displacements of markers across the fault as observed from topography and trenches are well-constrained and consistent, the relatively sparse nature of the point observations in the complex step-over zone gives rise to some ambiguity.

For this reason, 2D seismic and 2D + 3D GPR surveys were carried out on site. The main goals were to image the full complexity of faulting in and around the step-over zone and to put additional constraints on the spatial and temporal distribution of strike-slip and dip-slip rates at this location. Resulting crisp 2D and 3D GPR images reveal the multiple fault strands identified and inferred from the recent geomorphological study. Furthermore, newly revealed fault strands in the step-over zone can be traced throughout the 3D data volume, as well as an obliquely offset paleo-channel. Thirteen 2D GPR profiles across a 2.6-km segment of the AF, flanking the step-over zone, were able to pinpoint the exact location of the main AF strand. The 2D images also suggest there is a somewhat broader damage zone than initially thought. Excellent correlation between the GPR images and trenches confirms the reliability of the GPR data, allowing them to be used confidently to place new spatial and temporal constraints on slip rates.

DEVELOPMENT OF REGIONAL SEDIMENT MOBILITY MODELS

A. Carrizales¹ & J. Dix²

¹SGEES, Victoria University of Wellington, PO Box 600, Wellington.

²SOES, National Oceanography Centre, University of Southampton, United Kingdom
Adam.Carrizales@vuw.ac.nz

Development of viable sediment transport and hydrodynamic models on a regional-scale is crucial for the effective management of underwater resources and heritage, and examining historical coastal evolution. Recent work combines high-resolution bathymetric data (25 m) from the Goodwin Sands and Thames Estuary (UK) with industry-standard hydrodynamic modelling software (*MIKE 21*) to accurately predict net sediment transport direction and relative bed-level changes for each region.

Each of the two sediment mobility models consists of a tidally-forced hydrodynamic model, the output of which drives a decoupled sediment transport model. The primary method used to control hydrodynamic flow in the models is by varying the bed roughness coefficient (*M*), a parameter which relates the seabed type and morphology to current velocity. Iterative calibration of the hydrodynamic model against observational tidal and current flow data have shown that use of a high roughness coefficient is required to compensate for the drag influence of bedforms not resolved in the bathymetric data. However, all of the results from the calibrated hydrodynamic models lie within the standards set by the UK Environment Agency (\pm 10-20% of observed speeds).

Calibration of the sediment transport model results against high-resolution swath bathymetry shows general agreement between both the predicted sediment transport directions and the residual transport direction indicated by observed bedforms, showing a possible anti-clockwise rotation of the sandbanks. Sediment transport predictions from the Thames Estuary also agree with sediment transport direction inferred from bedforms, and show that in some regions of the Thames Estuary, the ambient tidal flow is insufficient to transport the dominant sediment fraction. This supports the hypothesis of the Eastern Thames Estuary being a relict river terrace landscape.

RELATIONSHIPS BETWEEN GEOCHEMICAL EVOLUTION, ERUPTIVE STYLES AND PRODUCTS ASSOCIATED WITH THE PHONOLITIC VICO VOLCANIC CENTRE, CENTRAL ITALY, WITH FOCUS ON THE FARINE FORMATION

R.A.F. Cas¹, G. Giordano², M.I. Laird¹

¹ School of Geosciences, P.O box 28E, Monash University, Clayton, VIC, AUS, 3800

² Dipartimento di Scienze Geologiche, Università di Roma Tre, 00146 Roma, Italy
lslay.laird@sci.monash.edu.au

Vico volcano is a well-developed Neogene-Quaternary phonolitic stratovolcano located at the northern edge of the Roman Magmatic Province, approximately 60 km north of Rome in central Italy. This basal part of the stratovolcano is predominantly composed of lavas, with a composite summit explosive caldera.

Vico Volcano had a complex history commencing at 419 ka and ending at 95 ka. Three main eruptive cycles have been identified within the Vico volcanic complex: the Rio Ferriera Synthem (419 – 400 ka), representing the initial effusive phase intermittent with minor explosive phases of activity; The Lago di Vico Synthem (305 – 144 ka), characterizing the major explosive caldera forming phase; and the Monte Venere Synthem (138 – 95 ka) which represents final effusive and phreatomagmatic volcanism.

Four major ignimbrite units have been identified in the Lago di Vico Synthem: Farine, Ronciglione, Sutri, and Caprarola Formations. Most of the units examined were leucite-bearing; however the Ronciglione Fm is leucite-free. The Farine Formation marks the initial caldera-forming phase and multiple lateral and vertical variations have been observed. Pyroclastic fall, and flow deposits of the Farine Formation outcrop to the west, north-west and north-east parts of the volcano. Pyroclastic fall deposits range in thickness from a 0.2 – 1.2 m in thickness, with the thicker deposits occurring to the north-east. The ignimbrite consists of at least two flow units, and includes lithic-rich lenses, where lithics are up to 3 m in diameter. One of these lenses is observed to the north-west of Vico caldera, approximately ~5 km from the source. Observations infer this brecciated lens to be a lag-flow breccia deposit. Farine spatter flow deposits, approximately 1 m thick, are also observed to the north-west of the volcano, and are often welded.

KEY WORDS: Ignimbrite; phonolite; caldera; Vico Volcano; Central Italy

BUBBLES AND BANGS: A VOLCANOLOGIST'S PERSPECTIVE ON MAGMA DEGASSING PROCESSES

K.V. Cashman

Dept. of Geological Sciences, Univ. Oregon, Eugene, OR, USA
cashman@uoregon.edu

Vesiculation is an unavoidable consequence of magma decompression; the extent to which bubbles travel with ascending magma or leave the system by separated or permeable flow will determine the nature of the ensuing eruption. Bubbles travel with the melt from which they exsolve if the rise time of bubbles through the melt (the 'drift velocity') is much less than the rise rate of the magma. Under these conditions, bubble expansion within the melt continues until sufficient bubble expansion causes coalescence and the development of a permeable network. Typical pumice vesicularities of 70-80% and permeabilities of $\sim 10^{-12} \text{ m}^2$ constrain this limit under conditions appropriate for subplinian to plinian eruptions (mass fluxes $> \sim 10^6 \text{ kg/s}$). Bubbles rise through the melt if the drift velocity exceeds the velocity of magma ascent. This condition is most easily met in volatile-rich, low viscosity (mafic) melts at low to moderate fluxes. At very low magma flux, magma eruption rate is determined by the extent to which magma is entrained and ejected by rising gases; when bubbles are too small, or rise too slowly, they may not break the surface at all, but instead may be concentrated in a near-surface layer. As the magma flux increases, segregation of bubble-rich from bubble-poor melt requires both longer conduits and lateral transport of degassed magma, explaining the simultaneous eruption of bubble-poor lava and vesicular tephra that characterizes violent strombolian activity. Magma degassing also causes crystallization; addition of crystals to rising magma will both slow upward bubble migration and change the size and shape of the bubble network (through deformation, coalescence, or bubble splitting). Thus future challenges for studies of gas migration through magmatic systems revolve primarily around multiphase flow behavior.

AUCKLAND: CITY OF ANOMALIES

J. Cassidy, C.A. Locke & R.H. Murray

School of Environment, University of Auckland, PB 92019, Auckland
j.cassidy@auckland.ac.nz

The Auckland volcanic field (AVF) and surrounding region are characterised by geophysical anomalies on a range of scales that highlight complexity at different crustal levels. Most notably, the AVF is coincident with regional magnetic and gravity anomalies that mark a major crustal suture and in particular, with a discontinuity marking a significant structural asperity. Here, the linear regional magnetic anomaly splays into a wide band of NNW-trending lineaments, arising from serpentinised shear zones in the upper crust, that may reflect a region of crustal weakness creating preferential permeability. A large gravity anomaly, attributed to a crustal block of high density that extends north from the AVF, displays subtle lineations of unknown origin across the Auckland isthmus. All these features have a NNW trend, probably reflecting inherited crustal structure. However, there appears to be no simple correlation between these lineaments and the locations of individual vents in the AVF that might delineate more shallow structural controls, perhaps as a consequence of other equally significant structural influences. Higher resolution geophysical data over the AVF show that the volcanoes and their deposits have a wide range of magnetic and gravity signatures indicating a variability of subsurface structure not necessarily evident in the surface geology. These anomalies reveal, for example, where the main centres of eruption are located, the presence of crater-filling lavas beneath both scoria cones and tuff craters, buried flows and the course of paleotopographic channels, and even information about eruption timing.

GEOTHERMAL DISCHARGES OF ARSENIC: DO SILICATES ADD INSULT TO INJURY?

H.K. Christenson & P.J. Swedlund

Dept. of Chemistry, University of Auckland, Private Bag 92019, Auckland.

hchr009@aucklanduni.ac.nz, p.swedlund@auckland.ac.nz,

Geothermal discharges into the Waikato River contribute large amounts of arsenic to the system. Another consequence of the geothermal inputs is high concentrations of silicic acid (≈ 40 ppm as SiO_2) which are double the worldwide average river value. Arsenic in river systems exists in solution and adsorbed onto the surfaces of iron oxides phases associated with the suspended and bed sediments. Silicic acid has been shown to decrease arsenic adsorption chemistry in a number of aquatic systems through competitive adsorption onto iron oxides. In most river systems approximately 50 % of the total arsenic in a water sample would be adsorbed onto the sediment iron oxide phases whereas in the Waikato River only 0 – 20 % of the arsenic is adsorbed. This paper tests the hypothesis that the unusually high concentrations of silicic acid in the Waikato River cause the unusually low arsenic adsorption through a competitive adsorption process. This hypothesis was tested in two steps. Firstly the amount of H_4SiO_4 associated with the sediment iron oxide phases was quantified. This is not a trivial task given that the sediment consists predominantly of silica phases. Sediments were extracted over time with ethylenediaminetetraacetic acid and data for the rates of dissolution allowed for the quantification of the silicic acid adsorbed on the iron oxides. The effect of this silicic acid on dissolved arsenic concentrations was then investigated using a surface complexation model to describe the competitive adsorption reactions on the iron oxide. Preliminary modelling shows that increasing silicic acid concentration in the water from 20 ppm to 40 ppm (as SiO_2) causes a decrease in the amount of adsorbed arsenic of comparable magnitude to the observed differences between the Waikato and other rivers. Therefore it appears high silicic acid concentrations in the Waikato River do contribute to high dissolved arsenic concentrations.

A HIGH RESOLUTION PALEO-CLIMATE AND –OCEANOGRAPHIC RECORD OF MIS 11 AS AN ANALOUGE FOR UNDERSTANDING THE CURRENT AND PAST (MIS31) INTERGLACIAL PERIODS

Kylie Christiansen¹, Joel Baker¹ and Lionel Carter^{1,2}

¹School of Earth Sciences, Victoria University of Wellington, Po Box 600, Wellington

²Antarctic Research centre, Victoria University of Wellington, Po Box 600, Wellington

Marine isotope stage 11 (MIS 11) was an interglacial stage that occurred at 0.428 to 0.397 Ma when Earth's orbital parameters were most similar to the present day interglacial. Primarily this study will measure trace element chemistry and stable isotopes of planktic foraminifera sampled from sediments in Ocean Drilling Program core 1123 and aims to provide new quantitative insights into the paleoclimatic and paleoceanographic change for the MIS 11 interglacial and provide insight into what lies ahead for the Holocene.

Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) will be used to measure *in situ* ratios of elements Li, B, Mg, Al, Mn, Zn, Sr and Ba/Ca in the CaCO_3 tests of the planktic species *Globigerina bulloides* and *Globigerinoides ruber*. These data can be used to quantify past surface and thermocline water temperatures as well as changes in oceanic water masses and ocean acidity using calibrations between ocean conditions and foraminifera chemistry previously established for modern foraminifera. Site 1123 is located at the northern limit of the Subtropical Front and as such records sensitively changes in the mixing of the two main surface water masses east of New Zealand – Subtropical and Subantarctic waters that influence the climate and marine biological productivity off eastern New Zealand. Trace element chemistry coupled with oxygen isotope measurements of the foraminifera will also be used to infer past changes in the the oxygen isotope composition of seawater in response to changes in global ice volume and temperature, and will thus highlight any changes in MIS11 surface water masses in response to melting or growth of Earth's cryosphere.

Results will be compared with the cooler super-interglacial MIS 31 (*ca.* 1.09 to 1.07 Ma) when significant collapse of the Ross Ice shelf and parts of the Antarctic ice sheets may have occurred. The comparison of MIS 11 and MIS 31 will enable a direct comparison of the changes in ocean temperatures and circulation, and global ice volume that took place in two Quaternary super-interglacial periods, which appear to have had markedly different effects on the Antarctic cryosphere.

REGIONAL STREAM SEDIMENT GEOCHEMICAL SURVEY DATA

A.B. Christie¹ & R. Carver²

¹GNS Science, PO Box 30368, Lower Hutt.

²GCXplore Pty Ltd, 67 Chelmsford Road, Mt Lawley, WA 6050, Australia.

t.christie@gns.cri.nz

New Zealand open file mining company stream sediment geochemical survey data are compiled in the REGCHEM (Regional Exploration Geochemistry) database managed by GNS Science (see <http://maps.gns.cri.nz/website/minmap>). These data relate to exploration surveys for metallic mineral deposits and are therefore concentrated in their most prospective areas: Northland, Coromandel Volcanic Region (CVR), Taupo Volcanic Region (TVR), Marlborough, west Nelson, West Coast, Otago and Southland.

We have carried out statistical analyses to generate contour maps of element concentrations for Coromandel, TVZ, West Coast and Otago. Anomalies related to mineral deposits, and regional variation of concentration related to geology are best developed in data for base metals such as copper, zinc and molybdenum. Elements such as gold, silver, and antimony, have some localised high concentration anomalies related to mineral deposits, but they have limited regional application, because of the large proportion of data below their detection limits. Other elements such as tungsten and tin have been analysed in only a few surveys, precluding their regional representation.

Inherent problems such as different sampling methods, analytical techniques and detection limits between the different mining company surveys highlight the need for new national multielement geochemical surveys. To test methods for the national surveys, a pilot stream sediment geochemical survey was carried out by GNS Science in a 220 km² area near Thames in the CVR and Hauraki Goldfield. Seventy samples were analysed for 50 elements, mostly by XRF. Some regional patterns are apparent: 1. As, Cd, Cu, K₂O, Pb, Sb, Se, and Zn exhibit anomalous concentrations mainly in the western part of the study area related to Au-Ag-Zn-Pb-Cu epithermal quartz veins and porphyry Cu occurrences; 2. Hg is anomalous in southern samples reflecting cinnabar occurrences; and 3. Ba and U are anomalous in the eastern samples, probably related to rhyolitic rocks.

LARGE SCALE NATURAL CONVECTION IN THE WAIRAKEI-TAUHARA GEOTHERMAL FIELD

E.Clearwater¹ & M.J. O'Sullivan¹

¹Dept. Of Engineering Science, University of Auckland, Auckland.

ecl011@aucklanduni.ac.nz

The Wairakei–Tauhara geothermal system, located within the Taupo Volcanic Zone, has been the subject of extensive geological and geophysical research, and many numerical modelling studies. In the present study the structure of large-scale convection in the Wairakei–Tauhara system is of interest. The variables investigated are the permeability structure, the topography and the heat sources. The data used for calibration are the surface mass flow and surface heat flow, based on pre-exploitation field data.

A three-dimensional model was created that is larger, deeper and simpler than current Wairakei–Tauhara models. It is large enough so that the Rotokawa geothermal field is also included within the model.

Many different numerical simulations were carried out using TOUGH2, exploring the effects of different permeability and heat input structures. The initial models had a very simple structure and were investigated mainly to confirm the effects already reported in literature of using different permeability structures. As further simulations were performed it was found that the most appropriate form of the large scale permeability structure to generate the required plume spacing was non-uniform and anisotropic. The non-uniformity was applied as an exponentially decreasing function so that the surface layers had a permeability value ten times that of the lower layers. Anisotropy was implemented with an x,y permeability five times higher than that in the z-direction. This, when combined with a cap rock layer near the surface, and a non-uniform heat flux as a bottom boundary condition, produced three plumes with surface outflows in approximately the correct locations to represent the Wairakei, Tauhara and Rotokawa geothermal fields. The mass and heat outflow for each of the fields shows a good correlation to the field data, although there is some extra surface outflow occurring between the Wairakei and Tauhara fields, at the Waikato River.

INFLUENCE OF DEEP CULTIVATION AND TRANSMITTER VOLTAGE ON THE RESPONSE OF AGRICULTURAL GROUND PENETRATING RADAR

M. Cockcroft¹, D.C. Nobes¹, T. Wilson¹ & Z. Whitman¹

¹Department of Geological Sciences, University of Canterbury, P.B. 4800, Christchurch.
david.nobes@canterbury.ac.nz

After the 4th of September 2010 Darfield earthquake, many near surface geophysical surveys were completed, which presented us with the opportunity to examine the impact on ground penetrating radar (GPR) profiles due to changes in survey parameters and in ground conditions. One paddock where the effects of the fault were significant was deeply tilled 4 times using a specialist “land rehabilitation” implement to reduce the topographic impacts of the fault and to fill in the surface “cracks”. GPR profiles were acquired before and after tilling, using a Sensors & Software pulseEKKO Pro with 100 MHz antennas, and using both 500 and 1000 V transmitting power.

The GPR profile acquired using the 1000 V transmitter power yields greater subsurface reflection energy than for the 500 V transmitting power, but the direct ground wave is “clipped”, i.e. the top of the radar wavelet is truncated. The clipped waveform can adversely affect migration and any attempts at deconvolution, because the top of the waveform has a sharp “corner” rather than a smooth wavecrest. In general, the same subsurface information can be obtained using more stacking of a lower power signal.

The effects of the deep tilling is reflected in an increase in the shallow velocity, due to reworking and compaction of the soil, and subsequent “pull up” of the reflectors immediately underlying the tilled zone due to the reduced two-way travel time. The deeper structure and features are largely unaffected.

This rapidly deployed GPR survey was able to provide information to farmers and the Canterbury Rural Recovery Group on the performance of the deep cultivation implement in remediating significant ground disturbance, in this case fault rupture, on high-intensity pastoral land. It also provides an important insight into the modification modern agriculture may have on transient geological disturbances in gravely soils.

MAGMA SYSTEMS BENEATH THE OKATAINA VOLCANIC CENTRE

J.W. Cole¹, C.D. Deering², R.M. Burt¹, R. Turnbull¹, N. Matthews³

¹Department of Geological Sciences, University of Canterbury, Private Bag 4800, Christchurch

²Dept of Earth and Space Sciences, University of Washington, Seattle WA 98195-1310, USA

³Department of Earth Sciences, University of Oxford, Oxford OX1 3PR, UK

The Okataina Volcanic Centre (OVC) has a protracted volcanic history that includes multiple phases of collapse during which rhyolitic ignimbrites have been deposited. Before and after these events there have been many rhyolite lava dome extrusions and explosive eruptions.

This paper reviews the information available from geochemistry of OVC lavas and plutonic blocks, erupted during some events, and comparison with older granitoid systems, to develop the following model for crustal magmatism.

First, dacite is extracted from a contaminated, mantle-derived basalt (at 50-70 vol.% crystals) within the lower to middle crust, which ascends into the cold upper crust (4-12 km) where it rapidly reaches a high crystallinity. The rhyolitic interstitial liquid in this dacite mush represents the melt-rich magma ultimately erupted at the surface. Andesite cumulate residue progressively form a root zone as rhyolite melt is extracted from the dacite mush at 50-70 vol. % crystals, which may eventually extend down to c. 12 km. The exhumation of significant volumes of granitoid plutonic lithics in recent eruptions indicates that portions of the underlying root zone have become either partially or fully frozen. Variations in geochemistry through time attest to frequent intrusions of rhyolite as sill-like bodies in the upper crust. We interpret the change in geochemistry that follows caldera collapse as a result of a partial or complete freezing of the mushy root zone induced by decompression. The high rate of extension within the OVC has undoubtedly played an important role in re-establishing a new dacite mush in the upper crust following caldera-collapse through relatively high level (up to 12 km) basaltic intrusions that provide the necessary mass and enthalpy. This model is equally applicable to the plutonic realm, like the Halfmoon pluton, Stewart Island, and strengthens the physical and geochemical bond between active volcanic systems and inactive plutons.

AN ACCELERATION IN NEW ZEALAND'S SEA LEVEL RECORD

T. Cole¹, J. Hannah¹, & R. Tenzer¹

¹Department of Surveying, University of Otago
colth306@student.otago.ac.nz

Since the later part of the 19th Century, tide gauge records indicate that global sea levels have risen with an average rate of 1.7 ± 0.3 mm/yr. Satellite altimetry records indicate that the rate of sea level rise between 1993 and 2010 was 3.2 ± 0.4 mm/yr. It is currently uncertain if this latter figure is indicative of an increased rate of rise, or the result of a periodic signal. In any event, if the future sea level rise is to be predicted accurately, it is of great importance that changes in the rate of sea level rise be detected as soon as possible.

This study utilises a variety of techniques, including least squares and Fast Fourier Transform analyses, to assess the sea level records from New Zealand's four longest tide gauge stations, located in Auckland, Wellington, Lyttelton and Dunedin, to detect any significant changes in the rate of relative sea level rise. It finds that Wellington's records demonstrate a relative acceleration of 0.0126 ± 0.0092 mm/yr², which is superimposed over the decadal and interdecadal signals that are present in the records. The records from the Auckland, Lyttelton and Dunedin tide gauges do not demonstrate significant accelerations. The longest significant signals that are present within the sea level records from Auckland, Wellington, and Dunedin have periods in the range of 45 to 50 years.

The establishment of continuous Global Positioning System stations at long-term tide gauge stations is imperative to isolate non-constant vertical deformations from the observed relative rates of sea level rise to detect accelerations, and also to isolate the absolute rate of sea level rise.

WINDFARM DEVELOPMENTS IN KARSTIC TERRAIN – AN EXAMPLE FROM THE PUKETOI RANGE, WAIRARAPA, NEW ZEALAND

J. Coleman¹, G. Alexander¹, & D. Rohan²

¹Beca Infrastructure Ltd, PO Box 6345, Auckland.

²Contact Energy Ltd, PO Box 10742, Wellington.
jacqui.coleman@beca.com

Wind farms are a sustainable renewable energy resource increasingly considered to meet future demands for energy in New Zealand. Geotechnical investigations have been undertaken to consent a wind farm that will comprise some 65 turbines of up to 3 MW each in the northern part of the Puketoi Range, Wairarapa, New Zealand. The project required the design of up to 34 km of access roads, a substation platform, the design and location of fill disposal sites and the search for aggregate that would be suitable for concrete production, use in road pavements, and to line cable trenches for internal transmission lines.

The Puketoi Range forms a prominent north-east trending escarpment, some 40 km in length, dominated by Pliocene to early Pleistocene bluff forming limestones interbedded with shallow dipping sandstones and siltstones of the Onoke Group. The geology of the project area was mapped in detail so as to form an understanding of each of the lithologic units and the structural geology of the northern part of the range that provides key controls on the site-wide hydrogeological conditions and inferred groundwater flow paths, proposed infrastructure layout, foundation design for the turbines and the location and design of fill disposal sites.

A karstic surface is commonly developed on the west dipping Te Onepu Limestone unit that occurs over much of the project area. The potential for collapse of sinkholes and other karstic features beneath key infrastructure is considered to be the most significant geological hazard for the project. Geotechnical investigations and detailed engineering geological mapping were targeted to specifically assist in understanding the karst features observed within the project area. The identification and mitigation of this hazard has influenced the design and location of access roads, turbine layout, options for turbine foundation design within karstic limestone, and stormwater and erosion controls during construction.

THE HUNTING OF THE MORPHOSPECIES

K. S. Collins¹, J. S. Crampton^{1,2}, M. J. Hannah¹

¹School of Geography, Environment and Earth Sciences, VUW, PO Box 600,
Wellington 6140

²GNS Science, PO Box 30368, Lower Hutt 5040, New Zealand
katiesusannacollins@gmail.com

Accurate biological taxonomy is a vital tool in many geological and biological disciplines. It is desirable and commonly assumed that identification to species level is both repeatable to a certain level of accuracy and phylogenetically informative. Both assumptions are commonly violated.

With fossil material, preservational biases generally leave only hard-part morphology for study. Much can be achieved with this limited dataset, although some groups of organisms are harder to identify based on hard parts alone than others.

Statistical morphometric methods provide an objective and repeatable way of quantifying biological morphology. In particular, analyses of landmarks (discrete, biologically homologous points) and outlines (continuous curves describing shape) both yield mathematical descriptions of morphological variation and relationships within a given sample of biological shapes. Utilising both captures more shape information than using either alone, but is not frequently undertaken. Stratigraphy, where well-constrained, can add a further source of data when attempting to resolve phylogenetic relationships between species.

This talk discusses the use of morphometrics to distinguish between species of New Zealand crassatellid bivalve and the incorporation of stratigraphic data into subsequent phylogenetic analyses, with the eventual aim of examining the mechanics of speciation in the group. This multistranded approach to taxonomy and phylogeny has the potential for use on other morphologically subtle groups.

FROM SEAFLOOR SPREADING TO SUBDUCTION: VOLCANO-TECTONIC EVOLUTION OF THE AUSTRALIA-PACIFIC PLATE BOUNDARY FROM MACQUARIE RIDGE COMPLEX SEAMOUNTS

C. Conway¹, J. Baker¹, H. Bostock², A. Verdier², R. Wysoczanski²

¹ School of Geog. Envi. & Earth Sci., Victoria University Wellington, PO Box 600,
Wellington

² National Institute of Water and Atmospheric Research, PO Box 14901, Wellington
conwaychri@myvuw.ac.nz

The Macquarie Ridge Complex (MRC) is a 1600 km-long bathymetric ridge which extends from 46°S to 60°S, forming the submarine expression of the Australia-Pacific plate boundary south of New Zealand. The MRC evolved from a mid-ocean spreading centre to a transform plate boundary during the Cenozoic. We combine results from high-resolution multibeam mapping and underwater towed-camera investigation of 10 seamount features along the MRC in order to document the evolution and current nature of the plate boundary.

The underwater images represent the first-ever remote observation of the MRC seafloor and reveal pillow, massive and sheet lava flows, consistent with effusive mid-ocean ridge volcanism that was extensive along the plate boundary. Bathymetry and backscatter maps reveal that this volcanism has ceased and oceanic crust has been sheared and accreted along the plate boundary to form the modern MRC. Strike-slip faults and seamount ridge crests trend parallel to the plate boundary as a result of cumulative transform and convergent relative plate motion. Seamounts distant from the plate boundary retain a primary volcanic form and may be the products of subduction of the Australian plate along the southern portion of the MRC. If so, the Australia-Pacific plate boundary south of New Zealand has undergone an evolution from seafloor spreading to subduction volcanism in less than 20 Myrs.

**MAGMA FORENSICS OF A 1.0 MA SUPERERUPTION: INSIGHTS FROM THE
KIDNAPPERS FALL DEPOSIT**

G.F. Cooper¹, C.J.N. Wilson¹, J.A. Baker¹

¹SGEES, Victoria University of Wellington, PO Box 600, Wellington.
coopergeor@myvuw.ac.nz

The Kidnappers eruption (1.0 Ma) from Mangakino Volcanic Centre is one of the largest eruptions (*ca.* 1200 km³ bulk volume) in the Quaternary of New Zealand. Crystal specific studies through a 4.0 m thick proximal section of the Kidnappers fall deposit, representing probably the first 60-70% of erupted material, yield insights into compositional zonation and the pre-eruptive state of the magma chamber. Hornblende thermobarometry shows a peak in rim temperatures of 780-810 °C, and pressures of 110-130 MPa, with cores showing a tail off to higher temperatures (up to 890 °C) and pressures (up to 260 MPa). Hornblende temperature modes are the same within uncertainties of temperatures from Fe-Ti oxide equilibria. Core and rim temperatures and pressures indicate a significant contribution of crystals from deeper (*ca.* 10 km) sources brought up to 3.5-6 km before eruption. Biotite and quartz abundances increase upward through the section (as reported previously for the 340 ka Whakamaru deposits), indicating the classical model of magma chamber evacuation where the most evolved composition is erupted first, cannot be applied to the Kidnappers. Two matrix glass populations are observed: 'high Ca' with 0.9-1.1 wt.% CaO and 'low Ca' with 0.72-0.82 wt.% CaO. The percentage of low Ca glass increases upwards through section and correlates with increasing biotite abundance. Coupled with mineral and melt inclusion chemistry, the relative abundances of mineral phases crystallizing from the melts suggest that either the magma chamber was tapped at different depths by two or more vents, or that any zonation within the chamber was laterally variable or disrupted prior to eruption, or that multiple chambers were evacuated. The two glass populations have implications for ongoing work regarding the relationship of different pumice types seen in the Kidnappers ignimbrite and identification of Kidnappers correlatives such as the Potaka Tephra.

SEISMIC IMAGING OF THE SUBTROPICAL FRONT, OFFSHORE OTAGO

J. K. Cooper, A. R. Gorman & M. H. Bowman

Dept. of Geology, University of Otago, P.O. Box 56, Dunedin.
cojo202@student.otago.ac.nz

The Subtropical Front (STF) is an important ocean boundary that separates warm, saline subtropical waters from relatively cool, fresh subantarctic waters. The region located off the southeast coast of New Zealand's South Island regularly exhibits evidence of nutrient transport across the STF that suggests that significant ocean mixing is occurring. Conventional oceanographic methods provide information about the general position and temperatures associated with the front in this area. However, these methods are limited in their ability to investigate the fine-scale structure of the front due to their spatially constrained nature. Seismic oceanographic methods, where conventional marine seismic methods are adapted to the imaging of ocean water masses, provide a means to image water body interactions in a high-resolution and spatially extensive manner.

We have capitalised on more than 30 years of seismic data acquired by the petroleum industry that are archived by Crown Minerals and publically available. In particular, we have made use of regional seismic lines recorded since the 1970's, the extensive Canterbury Basin surveys of 1982 and 1984, the Crown Minerals Dunedin 2006 survey in the Great South Basin, and new industry data collected in the Great South Basin as part of the current exploration activity there. Our reprocessing of these data focuses on the water column, rather than the sub-seafloor geology for which the data were originally collected. These datasets span the continental shelf and slope in water depths from a few metres to more than 1500 m; they are optimally located for investigations of water variability caused by interactions between shoreline processes and deep-water currents. Here we present initial results from this reprocessing initiative, in particular the successful imaging of interesting reflective water bodies on the Otago Margin, adjacent to and within the lower reaches of the Karitane and Taiaroa Canyons.

**ADVANCES IN INTERMEDIATE AQUIFER MONITORING TECHNIQUES AT
NGATAMARIKI GEOTHERMAL FIELD**

D. Coppel¹ & D. Wilson²

¹Western Energy, 3/66 Rakaunui Rd, Taupo.

²MightyRiver Power, POBox 245, Rotorua.
dane@westernenergy.co.nz

The Ngatamariki geothermal reservoir is overlain by a confined aquifer in rhyolite tuff and lava (the intermediate aquifer) that is separated from the deeper geothermal reservoir by argillically-altered volcanic rocks (the clay cap). The intermediate aquifer fluids are a mixture of meteoric and geothermal waters. The reservoir host rock is a faulted and hydrothermally-altered sequence consisting mostly of rhyolite lava and tuffs. This intermediate aquifer is separated from an unconfined near-surface fresh water aquifer (the shallow aquifer) by Huka Falls Formation sedimentary rocks which act as an aquitard. Owing to the fact that geothermal fluids recharge the intermediate aquifer, production from the geothermal reservoir could potentially drawdown the intermediate aquifer, and the intermediate aquifer has the potential to recharge the geothermal reservoir. In order to monitor and manage the intermediate aquifer a network of monitoring wells, each 300m-500m deep, have been installed. These wells require a monitoring system capable of detecting pressure, chemistry and temperature changes in the intermediate aquifer. Temperature monitoring is accomplished by the installation of a fibre optic cable (Distributed Temperature System) to obtain a complete well temperature profile of the well on demand. The DTS cable is accompanied by downhole pressure monitoring and fluid sampling systems to provide a complete monitoring system in one fixed instrument package.

IRON/DUST IMPACT ON THE SIZE OF *FRAGILARIOPSIS KERGUELENSIS*

G. Cortese¹, R. Gersonde², K. Maschner³ & P. Medley⁴

¹GNS Science, PO Box 30368, Lower Hutt.

²Alfred Wegener Institute for Polar and Marine Research, Bremerhaven (Germany).

³German Federal Agency for Nature Conservation, Vilm (Germany).

⁴CIRES, University of Colorado at Boulder (U.S.A.).
g.cortese@gns.cri.nz

The valve area of *Fragilariopsis kerguelensis*, the most abundant diatom species in the Southern Ocean, strongly changes in size in response to varying conditions in the surface ocean. We examined the link, both in two iron fertilization experiments and in sediment samples covering several glacial terminations, between size variability in this species and environmental conditions at the Antarctic Polar Front, including sea ice extent, sea surface temperature, and the input of eolian dust.

Larger valves are usually found during glacial times, and seem thus to be related to lower sea surface temperature and wider sea ice coverage. Moreover, our results indicate that there usually is a strong correlation between larger valve size and increased input of eolian dust to the Southern Ocean.

However, this correlation, valid for the fertilization experiments and for glacial terminations I, II, III and V, does not seem to be valid for termination VI, where size appears to be inversely correlated to dust input.

HYDROLOGICAL EFFECTS OF THE M_w 7.1 DARFIELD (CANTERBURY) EARTHQUAKE

S.C. Cox¹, T. Ezzy², T. Davie², J.C. Smith², D. Scott², P. White³, H. Rutter⁴, S.H. Song⁵

¹GNS Science - Dunedin, ²Environment Canterbury, ³GNS Science – Wairakei,

⁴Aqualinc Research Ltd., ⁵Korea Rural Research Institute

s.cox@gns.cri.nz

The M_w7.1 Darfield (Canterbury) earthquake on 4 Sept 2010 generated widespread hydrological effects; ranging from near-instantaneous coseismic liquefaction and changes in well levels, to more sustained (days to weeks) post-seismic changes in river discharge, spring flow and groundwater level. The scale and nature of response at any one locality, herein classified as being either near-field (<30 km) or far-field (>30km), for the most part reflects proximity to the Greendale fault and earthquake epicentre.

Near-field river level increases were recorded on the Canterbury Plains in the Selwyn, Heathcote, Avon, Halswell and Styx Rivers; and on Banks Peninsula in Kaituna River and Aylmers Stream. In recession prior to the earthquake, flows increased immediately afterwards, remaining anomalous for at least 1 day. Earthquake-related discharges were no more than those produced by normal rainfall events. Instrument shaking, lateral spreading, embankment collapse and liquefaction have affected recorded river levels, channel calibrations and discharge calculations. Surface water ponded locally throughout the near-field area. At the western end of the Greendale fault, a broad fold scarp ~1 m high lifted the Hororata River bed causing flow to divert and flood farmland. Far-field river flows were not noticeably affected, but waters were turbid throughout Canterbury.

Groundwater levels and pressures changed throughout Canterbury's alluvial aquifer system. Close to Greendale fault, a number of wells with deep water levels became artesian - some increasing by around 40 m. Near instantaneous step-changes were measured in other near-field monitoring wells, mostly positive level changes of up to 4 m, with few negative responses. Coseismic pressure responses were followed in some cases by a gradual recession back to pre-earthquake levels or in other cases to a sustained change in water level. Rapid level changes probably reflect co-seismic static strain or consolidation processes, whereas delayed response may be caused by changes in permeability. Some changes in yield/drawdown relationships have been observed and initial testing points to increased fine sediments in or close to the well, although wider-ranging changes to the aquifer couldn't be ruled out. Far-field groundwater changes have occurred in Tasman, Marlborough, and Southland, mostly water level drops of <1 m. Thermal springs in the Southern Alps were also affected, cooling through shaking-induced changes in permeability that caused subtle changes in the mixing of near-surface meteoric and deep upwelling fluids.

The potential for long-term effects on aquifer properties and the groundwater resource is yet to be fully understood, but remains a concern for a region so dependent on groundwater for domestic supply and agriculture.

EARTHQUAKE-RELATED THERMAL RESPONSES AT COPLAND WARM SPRING

S.C. Cox¹, D.T. Strong¹, A.G. Reyes² & R. Sutherland²

¹GNS Science, 764 Cumberland St, Private Bag 1930, Dunedin.

²GNS Science, 1 Fairway Drive, P O Box 30368, Lower Hutt.

d.strong@gns.cri.nz

Water temperatures and rainfall have been monitored since March 2009 at a warm spring in Copland Valley, Westland (-43.63S, 169.94E). The experiment aims to provide insight into crustal fluid-flow near the Alpine Fault, where rapid uplift and strong erosion of the Southern Alps perturbs the thermal structure of the upper crust, resulting in geothermal activity. Copland warm spring at Welcome Flat is one of the most strongly flowing of about sixty springs along the Southern Alps. Effervescent CO₂-rich water emerges in a pool which discharges water at 6 ± 1 litres/sec. Pool water temperatures typically fluctuate at background values between 56-58°C, with minor diurnal variation, but fall dramatically to ~40°C during heavy rainfall when deep upwelling fluids are diluted near-surface by shallow circulating meteoric water. Recovery to background temperatures typically takes 3-5 hours after rain stops falling, depending on the magnitude of the rainstorm.

The M7.1 Canterbury earthquake at 0436 am (NZST) on 4 Sept 2010, centred 175 km to the east of Copland, resulted in shaking intensities ~MM4 (weak-largely observed) in the area. Peak ground accelerations (PGA) in the nearby (within 40 km) seismometers were < 2.3 %g. Nonetheless, over the next five days the Copland spring cooled 1.1 ± 0.2 °C, with cooling delayed 140 ± 15 minutes after arrival of the seismic waves. The observed thermal response in the pool was very similar to a cooling decay that followed the M7.8 Dusky Sound earthquake on 15 July 2009. Centered 350 km to the southwest in Fiordland, this earthquake resulted in similar weak intensity of shaking in the area (~MM3-4) and low PGA's (0.5-2.1 %g). A slight warming of 0.2 ± 0.05 °C occurred for 180 ± 15 minutes, followed by a 0.9 ± 0.2 °C cooling over a five day period.

The thermal response of Copland spring to seismic activity is quite distinct from rainfall-related cooling. The main differences between the earthquake responses were that Canterbury earthquake-related cooling was perturbed by rainfall (between 5-7 September), did not show warming immediately following the earthquake, and started from background temperatures ~1°C lower (as the spring had not fully recovered from the 2009 earthquake). Our favoured interpretation is that seismic waves change the permeability of schist mountains adjacent to the spring, opening fractures and allowing greater quantities of cool surface water to be driven downwards by topographic head and mix with upwelling hot water. Time-lags between seismic wave arrival and the start of thermal responses observed at the surface reflect the time required for water to travel from the zone of mixing up to the surface and are currently a focus of fluid-flow modelling.

SOUTH VICTORIA LAND GEOLOGICAL MAP: FINAL STAGES

S.C. Cox¹, I.M. Turnbull¹, M.S. Rattenbury², D. Townsend², R. Jongens¹ & M.J. Isaac²

¹GNS Science, 764 Cumberland St, Private Bag 1930, Dunedin.

²GNS Science, 1 Fairway Drive, P O Box 30368, Lower Hutt.
s.cox@gns.cri.nz

GNS Science is in the final stages of developing a new 1:250,000 Geological Map and GIS dataset for South Victoria Land. The work integrates and summarises all previous geological work in the area between Fry Glacier in the north (~76°30'S) and Skelton Glacier in the south (~78°45'S), and from the Polar Plateau (158°E) to Ross Island (178°E). It is part of the "QMAP" Quarter-million Geological Map programme which has also completed a modern 1:250 000 geological map series of mainland New Zealand (<http://www.gns.cri.nz/research/qmap/aboutqmap.html>). For South Victoria Land, a comprehensive search and review of existing geological maps, databases, research papers and geological theses has been completed and information compiled at 1:50,000 on 46 sheets. Limited new fieldwork was carried out in some areas that were poorly known or had been particularly contentious (K105, Nov/Dec 2008). Geological data have been captured and stored in an ArcGIS® database, from which a high quality 1:250,000 scale geological map will be published.

Examples of three derivative products generated from the GIS dataset will be presented: (i) a simplified summary geology map that differentiates rocks primarily in terms of their age and composition; (ii) a cover sequence map showing the distribution of various glacial deposits; (iii) a basement geology map showing the variety of Cambro-Ordovician granites and schist. These maps exemplify a range in level of detail or complexity that can be generated in final hard-copy maps using a GIS, as distinct from the more detailed information held within the GIS dataset. When published the final geological map and CD will be accompanied by a high-quality text summarising the geology, including rock descriptions, tectonics and glacial history. Digital data will also be available for download and delivered through a webmap application. This product will be a highly visible testament to New Zealand's ongoing commitment to Antarctic science.

FOSSIL BIASES AND BIODIVERSITY: COMMON CAUSE ROLE OF SPATIAL STRUCTURING

J.S. Crampton¹, M. Foote², R.A. Cooper¹, A.G. Beu¹, S.E. Peters³

¹GNS Science, PO Box 30368, Lower Hutt, New Zealand.

²University of Chicago, 5734 South Ellis Avenue, Chicago, IL 60637, USA.

³University of Wisconsin-Madison, 1215 W. Dayton St., Madison, WI 53706, USA.
j.crampton@gns.cri.nz

Paleontology is concerned with the history of life on this planet. Our perceptions of biodiversity history are, however, influenced strongly by secular bias in the quality of the fossil record. Over the past decade, a number of studies have suggested that the relationship between bias and diversity is not simple. These studies have proposed that poorly understood, common-cause factors have affected simultaneously both the quality of the fossil record and *apparent* diversity history, on the one hand, and *true* diversity dynamics on the other. We have used New Zealand's relatively complete fossil record of Cenozoic shelf molluscs to examine the role of spatial structuring – of both diversity and environments – as a common-cause agent of true diversity change and biases in the fossil record. In all our analyses, we have controlled for uneven representation and sampling of the rock and fossil records through time.

We find significant, negative correlations between the clumpiness of shelfal deposition and the geographic range of species. In turn, the geographic range of species is related positively to evolutionary rate. At the same time, we find positive correlations between the clumpiness of shelfal *non*-deposition and the quality of the fossil record. These results, perhaps unsurprising, suggest that spatial structuring of the environment is indeed one important link in the common-causal chain between true diversity change and the nature of the fossil record. Other, as-yet unknown factors must also be operating, however, to explain a strong positive correlation between true extinction rate and the quality of the fossil record, a correlation that does not seem to be related to spatial structuring in the environment.

TWO-DIMENSIONAL MODELS OF THE TAUPO VOLCANIC ZONE

A. Croucher & M.J. O'Sullivan

University of Auckland, Private Bag 92019, Auckland.
a.croucher@auckland.ac.nz

The observed surface heat output from an east-west slice through the Taupo Volcanic Zone is matched using simple two-dimensional numerical models extending to a depth of 7 km, and a supercritical extension to the TOUGH2 simulator. Modelling indicates that permeability structure alone, with a uniformly distributed bottom heat input, is not sufficient to explain the observed bi-modal surface heat distribution. However, a simple fixed permeability structure, in combination with particular bi-modal bottom heat inputs, can set up a system of two stable convecting cells, which gives a good match to the observed surface heat output.

MODEL CALIBRATION: WHY USE MARKOV CHAIN MONTE CARLO?

T. Cui¹ & C. Fox² & M. J. O'Sullivan¹

¹Dept. of Engineering Science, The University of Auckland, Private Bag 92019,
Auckland

²Dept. of Physics, University of Otago, PO Box 56, Dunedin.
tcui001@aucklanduni.ac.nz

The aim of this work is to develop a method for automating the calibration of numerical models of geothermal fields, within the framework of Bayesian inference. Unlike the traditional optimization techniques that obtain a single point estimate of the unknown parameters, our approach summarizes all the feasible parameters that consistent with the field data through the posterior distribution. Markov chain Monte Carlo (MCMC) sampling, Metropolis-Hastings algorithm in particular, is used to draw samples from the posterior distribution. Then, answers to the calibration problem such as parameter estimation, derivation in the model predictions, and model reliability can be given by estimating the expected values of statistics of interest over these samples.

We apply this sample based approach to calibrate of a simple single-layer model of the feedzone of a well, using discharge test measurements of flowing enthalpy and pressure. This approach is able to make accurate model predictions and quantify the uncertainty in the prediction. Based on the same data set, sample based approach is compared to the optimization package ITOUGH2, and shows advantages on robust parameter estimation and accurate uncertainty quantification.

MANTLE WEDGE FLUIDS UNDER N-E NORTH ISLAND, NEW ZEALAND

F Davey, M Reyners, J Ristau

GNS Science, PO Box 30368, Lower Hutt

F.Davey@gns.cri.nz

Crustal seismic reflection data across the eastern Bay of Plenty and Raukumara Peninsula margin image an intriguing localised zone of strong reflectivity at a depth of about 35 - 40 km (12 – 16 s twt) that coincides with a local increase in seismicity. The zone lies between the Hikurangi subduction zone along eastern North Island and the extensional back-arc basin within central North Island (Taupo Volcanic Zone). It is within the mantle wedge as Moho is clearly imaged on the seismic reflection data and the top of the subducting slab is clearly defined by seismicity. The distribution of seismicity within the region shows the occurrence of two similar local seismicity clusters in the mantle wedge, about 60 km to the northeast and to the southwest of the eastern Bay of Plenty zone, aligned sub-parallel to the plate boundary strike. In 3D these zones of seismicity form clusters about 10 - 15 km in diameter in the mantle wedge, from the subducted plate at 50 km to about 30 km depth. Tomographic inversions of seismicity data show that the hot spots coincide with low V_p , low V_p/V_s and low Q_p . The strong local reflectivity and concentrated seismicity suggest a partial melt or fluid origin. Focal mechanisms are variable but all have a nodal plane close to vertical, consistent with near vertical fractures and flow. The subducted plate is too shallow here for normal back-arc melt generation, but the lateral spacing of the inferred columnar flow suggests convective flow or density driven diapiric upwellings within the mantle wedge nose. The cause of the hotspots is inferred to be fluid, possibly partial melt, resulting from dewatering of a serpentinised mantle wedge nose, but the cause of the limited lateral extent along the plate margin is unknown.

THE ROLE OF TRANSFORM FAULTS IN GONDWANA BREAK-UP IN THE NEW ZEALAND REGION

B. W Davy

GNS Science, PO Box 30368, Lower Hutt.

b.davy@gns.cri.nz

Following Cretaceous entry of the Hikurangi Plateau into the northern Chatham Rise convergent margin and the consequent jamming of subduction at this margin, extension, which had previously occurred at the Osbourn Trough spreading ridge, was transferred via the Wishbone Ridge strike-slip fault complex into the Bounty Trough region of the Gondwana interior.

By matching the Bollons Seamount location on opposing New Zealand-Antarctic rifted margins and by re-locating it into the original Gondwana margin, it has been possible to use the satellite gravity data and published magnetic anomaly data to constrain and establish a reconstruction model of Gondwana break-up which explains the roles of the De Gerlache Gravity Anomaly, Marie Byrd Land seamounts and the South-East Chatham Terrace.

Crucial in the break-up process has been the role of the transform Wishbone Ridge Fault, and possible sub-parallel faults, and their extension southwest along the sub-Antarctic margin into the Ross Sea embayment.

HIGH RESOLUTION MARINE GEOPHYSICAL SURVEYING OF THE SHALLOW WATER BAY OF ISLANDS AND LINKED 3D-VISUALISATION DATASETS

B. W Davy

GNS Science, PO Box 30368, Lower Hutt.
b.davy@gns.cri.nz

Imaging and interpretation of the shallow-water (< 30 m) seafloor and upper 20 m beneath the seafloor has made dramatic advances over the last decade with the development of high resolution marine geophysical survey technologies. Vertical resolutions of 0.2 m or better are now realisable for both seafloor topography using modern and portable swath bathymetry systems, and for sub-seafloor sedimentary horizon morphology using Chirp echo-sounders.

In October/November 2009 GNS Science collected 220 line-km of Chirp seismic data and 170 km of magnetic data as part of the Oceans 2020 study of the Bay of Islands. The chirp seismic images the sedimentary section deposited over the last glacial erosion surface and the present and past occurrences of sea floor channelling and bottom current erosion. Many of the prominent features in the post-glacial sedimentary sequence reflect the distribution, migration and escape of gas – probably of biogenic origin.

The sediment-sea floor interface is well imaged, with gas/water escape structures identifiable both in seafloor morphology and water column effects. Within the water column large numbers of schools of fish are identifiable. Fish are often found where fluids are interpreted to be escaping from the sea floor.

Eighteen magnetic survey lines reveal northwest-oriented ridges and a sedimentary basin in the central bay, and a northwest-trending fault across the mouth of the bay.

This data combined with swath bathymetry, seafloor imagery and boomer seismic data all collected by NIWA provides a multi-faceted interpretation of the seafloor and sub-seafloor in the Bay of Islands. Combining all the survey data sets into a 3-Dimensional visualisation package provides an intuitively simple link between the many datasets. With the imminent availability of swath bathymetry systems that can image features within the water-column, the approaching decade will see links established between subsurface sedimentary structure, seafloor habitat and overlying water-column contents.

EVOLUTION OF CENTRAL WEST COAST FLOOD PLAINS DURING THE LAST 120 kyr

R. Davy, T. Stern & J. Townend

SGEES, Victoria University of Wellington
davyrich@myvuw.ac.nz

The rugged topographic relief of the central West Coast reflects ongoing interplay between active tectonic and climatic processes. Major geomorphologic features have formed in response to ongoing convergence between the Pacific and Australian continental plates. The principal locus of this collision is the transpressive Alpine Fault. Slip rates on timescales of hundreds of years have been determined using paleoseismic evidence, and on timescales of hundreds of thousands to millions of years on the basis of offset late Quaternary features. Using geophysical techniques, we are endeavouring to bridge these estimates by determining the slip rate of the central Alpine Fault on timescales of tens of thousands of years.

In this study, we are examining the last 120 kyr history of offset on the Alpine Fault by determining the structure and geomorphology of deeply incised river valleys using gravimetric, seismic and magnetic methods. By examining how the lower reaches of three major rivers — the Wanganui, Whataroa, and Waiho — have been translated with respect to their channels on the eastern (hanging wall) side of the Alpine Fault, we are endeavouring to quantify horizontal fault displacement in each catchment.

To date, we have collected 143 new gravity measurements (59, 65, and 19 in the Wanganui, Whataroa, and Waiho valleys, respectively) on the western (footwall) side of the Alpine Fault. This yields a total of 714 measurements spanning the three catchments when existing data is incorporated. Preliminary results for the Whataroa reveal a 550 m deep channel dextrally offset by ~1 km with respect to the hanging wall of the Whataroa River. The next phase of this project will involve modelling several two-dimensional transects that serve as constraints for three-dimensional modelling of the three flood plains.

INVESTIGATION OF GEOTHERMAL CONVECTION IN EVOLVING PERMEABILITY REGIMES USING NUMERICAL MODELLING

D. E. Dempsey¹, R. A. Archer¹, J. V. Rowland² & S. M. Ellis³

¹Dept. of Engineering Science, University of Auckland, Private Bag 92019, Auckland.

²School of Environment, University of Auckland, Private Bag 92019, Auckland

³GNS Science, 1 Fairway Drive, Lower Hutt
d.dempsey@auckland.ac.nz

The Taupo Volcanic Zone (TVZ), an extensively faulted and fractured region due to high rates of tectonic extension ($7-15 \text{ mm yr}^{-1}$), hosts the vast majority of New Zealand's convective geothermal systems. The rifting and intruded crust permits an elevated heat flux ($\sim 700-800 \text{ mW m}^{-2}$) while the high fracture permeability allows for circulation of largely meteoric fluids. Fracture permeability is necessarily dynamic, maintained through fault rupture and associated stress redistribution, deep viscous creep, or inhibited by mineralization, hydrothermal alteration or pressure drawdown.

Computational models of geothermal convection, while invoking spatially complex and reasonably well constrained permeability distributions, typically do not require a description of their temporal evolution. Changes to permeability structure, particularly those associated with seismicity or alteration, typically occur at rates appreciable on geologic timescales and not necessarily relevant to commercial interests. Other mechanisms, specifically fracture closure associated with pressure drawdown, may present more immediately and warrant closer investigation.

We use the finite element fluid flow code, FEHM, to describe general, steady state, 2-D convection cells, conforming to heat flow and permeability properties representative of the TVZ. The permeability distribution is then perturbed under a variety of physically realistic scenarios including; deep ($\sim 7 \text{ km}$) compression anomalies corresponding to fault rupture; enhanced permeability at surface zones exhibiting high plastic strain; and a gradual reduction in permeability where high mass flow at critical temperatures may effect alteration or mineralization. The models described here investigate general hydrothermal convection over geologic timescales ($\sim 1-100 \text{ ka}$) and at TVZ spatial scales ($50 \times 8 \text{ km}$) rather than the convective structure of individual geothermal systems or their behaviour over commercial timescales (30-100 years).

STRESS/STRAIN CYCLING AND DEFORMATION MODES ON TVZ NORMAL FAULT SYSTEMS: INSIGHTS FROM NUMERICAL MODELLING

D. E. Dempsey¹, S. M. Ellis², R. A. Archer¹ & J. V. Rowland³

¹Dept. of Engineering Science, University of Auckland, Private Bag 92019, Auckland

²GNS Science, 1 Fairway Drive, Lower Hutt

³School of Environment, University of Auckland, Private Bag 92019, Auckland
d.dempsey@auckland.ac.nz

Tectonic extension, associated with rifting in the Taupo Volcanic Zone (TVZ), is the primary forcing behind the widespread normal faulting and associated seismicity in the region. Finite element models of an extending crust conforming to a visco-elasto-plastic rheology are used to investigate the seismic cycle of normal faults and fault arrays. A 2-D, plane strain crust, subject to 12 mm yr^{-1} extension and hosting a variety of fault architectures, has been investigated. Fault slip behaviour is prescribed by varying fault friction parameters, with cyclical rupture occurring every 300-1000 years. Frictional fault slip occurs above the brittle-ductile transition (BDT), which arises naturally from the prescribed material properties, with viscous creep the dominant mechanism below the BDT. Co-seismic deformation near the fault walls is rigid body in the upper crust ($\sim 0-7 \text{ km}$) and accommodated by elastic deformation in the mid-crust ($\sim 7-10 \text{ km}$). Post-seismic deformation is primarily viscous creep beneath the fault, and is driven in part by the elastic stresses developed during fault slip. This approach has previously been used to model the seismic cycle of the Alpine thrust fault (Ellis et al., 2006).

As a region of widespread geothermal activity, the TVZ represents a unique environment to explore the interactions between tectonism and hydrothermal flow. The mechanical models described here have been developed to investigate stress changes near faults that may be pertinent to models of fluid flow. Specifically, the region of compression that develops in the mid-crust during elastic accommodation of the fault slip above has implications for fracture permeability, pore dilation and pore fluid pressure changes. Further, plastic straining occurring in the hanging wall may indicate the development of antithetic faulting, further altering the permeability structure by opening additional fluid conduits to the surface.

THE GEOTHERMAL GAME

J. Dohaney¹, T. Powell², D. Gravley¹, & B. Kennedy¹

¹Geological Sciences, University of Canterbury, PB 4800, Christchurch.

²Mighty River Power, PO Box 90399, Auckland.

jacqueline.dohaney@pg.canterbury.ac.nz

Geothermal energy is approximately 10% of the national energy budget in New Zealand, sourced from high temperature reservoirs within the Taupo Volcanic Zone. It is a 'green' resource and a potential source of employment for graduating geology students. Interviews with geothermal professionals have identified scientific, economic and social issues that energy companies must take into consideration when performing exploration practices. These issues are often not taught in the geological curriculum. A problem-based simulation was designed in 2010 as part of the Frontiers Abroad Programme to teach undergraduate students about geothermal resource exploration. Students (n=12) were broken up into several groups and instructed to work together as a geological team in order to target geothermal anomalies. Geological data was given to the teams iteratively, in a multi-stage process. At the end of each 'stage', students presented their analyses to the 'Board of Directors' which was made up of geothermal professionals who played realistic stakeholder roles. A problem-based learning strategy was used which includes other pedagogical elements such as: 1. collaborative and authentic learning, 2. role-play, and 3. instant, iterative feedback from 'experts'. Each of these pedagogical design elements should help students develop 'real-world' knowledge and skills, such as: a. geochemical characterization of geothermal waters, b. exploration and production well targeting, c. proven resource estimate calculation, d. logistical and budgetary limitations, and e. community and culturally-related considerations (e.g. consulting with Māori Iwi leaders and/or land owners). Preliminary data were collected in order to characterize student engagement from this activity. Observation data indicated that students were highly engaged and student feedback was very positive indicating that students were excited about learning this applied topic. Future iterations of 'The Geothermal Game' will allow us to refine the authenticity of the simulation, and quantify student engagement in order to develop a widely accessible virtual version.

THE DIFFUSE LAYER MODEL: A TOOL TO UNDERSTAND NUCLEATION OF SILICA SCALE ON METAL SURFACES

R. Dol Hamid^{1,2}, P.J. Swedlund¹, G.M. Miskelly¹

¹Dept. of Chemistry, University of Auckland, Private Bag 92019, Auckland.

²School of Chemistry and Environmental Studies, Universiti Teknologi MARA,

Malaysia

rdol003@aucklanduni.ac.nz

The nucleation reactions leading to silica scale formation can occur in solution or at a surface. For example H_4SiO_4 can form Si-O-Fe linkages at iron hydroxide groups ($\equiv FeOH$) present on iron oxides on metal surfaces. The adsorbed H_4SiO_4 can then form Si-O-Si linkages in such a way that the iron oxide surface acts as a template for the formation of polymerized silica. In this study H_4SiO_4 polymerization on iron oxide surfaces was investigated using Attenuated Total Reflectance Infrared (ATR-IR) and the Diffuse Layer Model (DLM). Iron oxide suspensions were equilibrated at ambient temperature with H_4SiO_4 at a pH of 4, 7 and 10. ATR spectra of the iron oxide pastes were measured to quantify the various surface species present as a function of surface Si concentration (Γ_{Si}) and pH. The surface H_4SiO_4 can be monomeric or a linear oligomer with IR bands at 945 and 1009 cm^{-1} , respectively. The DLM was used to understand the effects of pH and Γ_{Si} on H_4SiO_4 polymerization on the oxide. Using monomeric and trimeric Si surface complexes ($\equiv FeH_{(3-n)}SiO_4^{(n)}$ and $\equiv Fe_2H_{(6-n)}Si_3O_{10}^{(n)}$ respectively) the DLM could correctly predicted the isotherms and the surface species distribution. At each pH the percentage of the adsorbed Si present as monomers decreases with an increase in Γ_{Si} while at a given Γ_{Si} the % monomeric silicate is highest at pH 10 and lowest at pH 4. The reason the pH affects the % of monomeric silicate is evident from the DLM equations and the isotherms. At a given Γ_{Si} the $[H_4SiO_4]$ is higher at lower pH. The H_4SiO_4 stoichiometry coefficient is 1 for monomer adsorption and 3 for trimer adsorption so, at a given Γ_{Si} , a lower pH favours trimer adsorption.

**TRACING GEOTHERMAL VENT AND FRACTURE PATHWAYS IN THE SHALLOW
SUBSURFACE USING GROUND PENETRATING RADAR**

A.J. Dougherty & B.Y. Lynne

Institute of Earth Science and Engineering, Private Bag 92019, Auckland 1142.
a.dougherty@auckland.ac.nz

Fractures act as vents allowing gases and thermal water to discharge at the surface from deep geothermal reservoirs. Knowledge of these geothermal environments, and the faults they run along, has been limited to deep geophysics and exposures available for surface mapping. The aim is to display the utility of ground-penetrating radar (GPR) to image vent and fracture pathways within a geothermal context. GPR has been successfully utilized in many geologic settings, including mapping rock fractures, but our research is the first to utilize this geophysical technique in a range of geothermal environments.

Hot spring water discharges through vents often along fractures to form siliceous sinter or carbonate travertine hot spring rocks. These vents may self seal overtime, but the sinter or travertine deposit and their geothermal source at depth can be preserved for thousands of years after hot spring discharge ceases. Subsequently these hot spring rocks can become fractured with potential as a gas-migration pathway. Since this formative hot spring water and ascending gases are associated with a deeper geothermal resource, the directionality of these conduits contributes to our understanding of the deeper reservoir.

Our initial research in the United States and New Zealand showed that GPR was successful in imaging sinter and travertine deposits to depths greater than 7 meters with decimetre resolution. Geophysical records of vents and fractures exposed in sinter outcrop compare well with the geological cross-sections. GPR profiles over vents and fractures exposed at the surface traced the trend of these features into the subsurface. GPR collected over a diffuse area of steaming ground revealed the lineation of its source fracture not obvious at the surface.

This novel application of GPR proved effective in mapping the spatial extent of fractures and vents within hot spring rocks providing potential to assist in the exploration of blind geothermal systems.

**STRATIGRAPHIC AND STRUCTURAL ELEMENTS OF THE SOUTHERN PAEROA BLOCK,
TAUPO VOLCANIC ZONE**

D.T. Downs¹, J.V. Rowland¹, & C.J.N. Wilson²

¹School of Environment, University of Auckland, Private Bag 92019, Auckland
²SGEES, Victoria University, PO Box 600, Wellington
d.downs@auckland.ac.nz

The Taupo-Reporoa Basin (TRB) and adjacent Paeroa Block are part of the actively rifting continental crust of the Taupo Volcanic Zone (TVZ). However, their stratigraphic and structural context are poorly understood, making it difficult link them in context to Taupo Fault Belt structures to the west. Here we present preliminary field observations of the surface stratigraphy and structures from the southern Paeroa Block.

Strata on the eastern side of the southern Paeroa Block consist of interbedded volcanoclastic and lacustrine deposits. The basal volcanoclastic unit is an ignimbrite containing abundant lithic clasts of black and pink-tan welded tuff, and rhyolite lava. Overlying this ignimbrite are silty, often pumiceous volcanoclastic lacustrine sediments with the previously named Mihi Breccia capping the hills. The breccia is massive to coarsely laminated and contains abundant intraclasts. Soft-sediment deformation structures, clastic dikes, and prismatic jointed pumiceous clasts in this sequence imply syneruptive sedimentation into a lacustrine environment.

The Paeroa Fault scarp exposes >600 m thicknesses of the ~340 ka Paeroa subgroup ignimbrites, but these units are absent south of Te Kopia geothermal field, and inferred to be down-faulted across an ENE-WSW trending structure beneath the southern Paeroa Block. To the south lacustrine and fluvial deposits are present, which are correlated with the Waiora Formation (Huka Group) within the TRB geothermal fields.

Dips vary in direction, and several smaller structural domains may be present in the southern Paeroa Block and/or vent features and constructional volcanoclastic landforms may be present. Linear features on topomaps and digital elevation models have been identified, trending NE-SW (TVZ orientation), NNW-SSE, and ENE-WSW. How these features correlate with faults in the TRB geothermal fields is uncertain. Fault patterns at Broadlands-Ohaaki, Ngatamariki, and Rotokawa trend parallel to the NE-SW trend of the TVZ with only sparse NW-SE trending structures proposed, with unknown amounts of displacement.

INTEGRATING SCIENCE ADVICE INTO THE EMERGENCY DECISION-MAKING PROCESS DURING NATURAL HAZARD EVENTS

E.E. Doyle & D.M. Johnston

Jnt Ctr for Disaster Research, Massey University/GNS Science, POBox 756,
Wellington.
emmadoyle79@gmail.com

A number of critical emergency management decision-making challenges arise in the lead up to, during, and after natural hazard events. Successful decision-making during these events is fundamentally dependent upon the situational awareness of personnel within local, regional and national Emergency Operations Centres (EOCs/ECCs). This is their assessment and understanding of the available information, the definition of the problem at hand, and the time and risk pressures. Implicit in this understanding is the use of scientific information and advice, which requires a rationalisation and integration of the wide range of scientific opinions, model outputs and outcome scenarios. Recent emergencies and national exercises have tested the provision and integration of science advice into the emergency management sector. The N.Z. Cabinet directed national "Exercise Ruaukoko" was run in 2007/2008, to comprehensively test the local, regional and national arrangements for dealing with the lead up to a volcanic eruption in the Auckland metropolitan area. Key recommendations from this exercise were for the refinement and co-ordination of scientific advice from "one trusted source", and the need for protocols for communicating probabilities and uncertainties. In N.Z., "Science Advisory Groups" (SAGs) have been identified as the pathway for the formation and dissemination of this advice to EOCs. However, there is currently limited understanding of how this information is effectively used during the decision-making process of the volunteer EOC personnel. We present planned investigations, to a) identify the different perceptions of uncertainty and probability phrasing, and b) explore how the presentation style of the scientific information and the methodology for forming a consensus affects the situational awareness and decision-making effectiveness of EMOs during exercises run in our EOC lab.

STRATIGRAPHY AND SEDIMENTOLOGY OF PLIOCENE LIMESTONES, MAHIA PENINSULA AREA, NORTHERN HAWKE'S BAY

Michele M. Drinnan and Campbell S. Nelson

Dept. of Earth & Ocean Sciences, University of Waikato, Private Bag 3105, Hamilton
mml9@waikato.ac.nz

The Opoiti, Whakapunake and Tahaenui limestones (5.28-3.0 Ma) are cool-water shallow-marine carbonates that formed upon active anticlines within the Hikurangi margin during the Pliocene. Their coarse skeletal fraction is typically dominated by barnacle plates with brachiopod, pectinid and oyster valves. Twelve sedimentary facies have been established based on texture and composition, namely limestone (L1-L3), sandstone (S1-S4), mudstone (M1-M4), and volcanoclastic (V1) facies.

Opoiti Limestone occurs on Mahia Peninsula and Mt Moumoukai as a bedded, 30 m thick, moderately dipping (25°W), sand-rich unit with common brachiopods and mudstone clasts (L1-L3). The lower contact with mudstone (M1) is sharp. No upper contact was observed. Petrography ranges from bioclastic arenite to poorly washed biosparite. Carbonate content <66%; siliciclastic modal size 140 µm (fine sand lower).

Whakapunake Limestone (L2, L3) on Mahia Peninsula is 70 m thick and thinly interbedded with a unique mudstone-clast bearing shelly sandstone (S4). Storm emplacements are the likely depositional mechanism for this facies type. No lower contact was observed. Upwards, the limestone grades via interbeds into shelly sandstone (S2). Petrography ranges from packed biomicrite to poorly washed biosparite. Carbonate content <78%; siliciclastic modal size 200 µm (fine sand upper).

At Nuhaka, Tahaenui Limestone (L1, L2) unconformably overlies mudstone (M1), while the upper contact grades into sandstone (S2). At Moumoukai, it unconformably onlaps the Opoiti Limestone. It is dominated by coarse barnacle plates with interparticle isopachous sparite rims and microbiohermic micrite. Petrographically a rounded biosparite or packed biomicrite. Carbonate content <90%; siliciclastic modal size 130 µm (fine sand lower).

The limestone units are laterally discontinuous and lensoidal, and are enclosed by thick mud-rich (M1-M4) to locally sandy (S1-S4) facies, along with occasional volcanoclastic beds (V1), referred to Mangaheia Group mudstone lithotypes A, B, C or D, depending on stratigraphic position.

**EXTENSION AT A COLLISION-SUBDUCTION TRANSITION: NEW INSIGHTS FROM
TIMOR**

B. Duffy¹ & M. Quigley¹

¹Department of Geological Sciences, University of Canterbury
brendan.duffy@pg.canterbury.ac.nz

New fault kinematic data from the synorogenic Viqueque Megasequence in East Timor provide insight into the evolution of the Australia/Asia plate boundary in the Banda Region. Striae measured in the Viqueque, Laleia and Marobo Basins of East Timor demonstrate dominant extension, with little compressional deformation. NE-SW (arc-parallel) extension is associated with approximately E-W directed dextral strike slip in the Viqueque and Laleia Basins. The Marobo Basin was extended in a dominantly top-to-the NW direction, with some strike slip motion on the SE side of the basin. Based on the relationship between our data and the recently published GPS data for the region, we suggest that this transtensional deformation is related to the differential plate motion caused by collision and westward-progressing accretion of the eastern Banda Arc to the Australian margin.

MARINE ISOTOPE STAGE 7 – OCEAN RESPONSE TO A WARMER WORLD

B. Duncan¹, L. Carter¹ & G. Dunbar¹

¹Antarctic Research Centre, Victoria University of Wellington, P.O. Box 600,
Wellington 6012
bellsduncan@gmail.com

One of the key questions facing environmental change science is “How will the ocean respond to the present phase of warming climate?”. Satellite observations show ocean change in a warming world is accompanied by increased algal blooms including nannofossil coccolithophores that contribute to the base of the marine food chain. Such observations, however, span a few decades and a longer, more representative record of plankton change may be derived from the sedimentary archives of past warm climates.

Marine Isotope Stage (MIS) 7 at 191-243 Ka is the penultimate interglacial and may provide an analogue for future climate change. Marine sediment cores P71 from north of New Zealand (33°51.3'S, 174° 41.6'E) and ODP 1120 from Campbell Plateau (50°3.803'S, 173°22.300'S) show abrupt switches from foraminiferal-rich to coccolith-rich sediments in MIS 7, indicating a major change in plankton productivity. In the Southern Hemisphere, the highest insolation values in the last 1 million years occur during MIS 7a (~210 Ka). This may have affected ocean productivity, as certain coccolithophore species are unusually tolerant of high irradiance and can outcompete other plankton. P71 and ODP 1120 are located on either side of the Subtropical Front, and can provide a comparison between changes in Subtropical and Subantarctic water masses. This study aims to identify what caused the switch in plankton by reconstructing conditions in these major water masses during MIS 7.

The threshold conditions responsible for these changes will be determined by using foraminifera to establish an oxygen isotope chronology and sea surface temperatures from Mg/Ca measurements. Water mass changes will be inferred from stable isotopes and trace elements including Zn and Ba. The total and relative species abundance of coccolithophores will also be identified. By investigating the paleoenvironmental conditions that caused the nannofossil blooms in MIS 7 an estimate of future impacts may be achieved.

KERMADEC ARC MINERALS GEOPHYSICAL CRUISE: PRELIMINARY SEISMIC RESULTS

J.D. Eccles¹, G. Lamarche², R. Wysoczanski², I. Wright³, F. Caratori Tontini⁴, M.R. Clark², J. Mountjoy², D. Amyes², P. Gerring², C. Kenedi¹, J. Mitchell², F. Muccini⁵, A. Verdier², S. Wilcox², S. Wormald³ & C. Castellazzi²

¹Institute of Earth Science and Engineering, University of Auckland

²NIWA, Wellington ³National Oceanography Centre, UK

⁴GNS Science, Lower Hutt ⁵INGV, Italy

j.eccles@auckland.ac.nz

The KARMA (Kermadec ARc MinerAls) voyage was undertaken on the R.V. Tangaroa in May 2010. Data acquisition included ~830 km of seismic reflection profiling across the Kermadec Arc and back-arc region. Seismic data were acquired at three different scales; regional lines across and along the arc and back-arc, volcano-scale lines across the Brothers and Rumble II complexes and pseudo-3D data acquisition across the hydrothermally active and mineralised NW rim of the Brothers caldera. The interpretation of these lines with preliminary processing will be discussed with reference to geomorphic features observed on the seafloor by multi-beam bathymetry. The geometry and lithologies associated with such volcanic terrains are notoriously challenging for seismic techniques and these challenges, and strategies for addressing them, will be introduced.

CORING AND TUNNEL BORING MACHINE SEISMICS: ANDALUCIA, SPAIN

J.D. Eccles¹, M.J. Jurado², P. Leary¹, P.E. Malin¹, L. Wotherspoon³, C. Segura⁴, E. Martin⁴ & A.I. Lopez²

¹Institute of Earth Science and Engineering, University of Auckland

²CSIC, Institut de Ciències de la Terra Jaume Almera, Barcelona, España

³Department of Civil and Environmental Engineering, University of Auckland

⁴DRAGADOS, Madrid, España

j.eccles@auckland.ac.nz

Blindly striking fluid-bearing zones remains a major hazard for tunnelling projects but efforts to see ahead of tunnelling would be more widely applied if such methods did not interrupt or interfere with the tunnelling operations. An array of sixteen 3C seismometers was deployed in a horizontal borehole parallel to, and slightly ahead of, a new tunnel in Andalusia, Spain, and recorded phases of coring and machine tunnelling along, and past, the array. Three component damped geophones, effectively accelerometers, were also installed on the drilling rig and tunnel boring machine. Although initial tunnelling at this site did not encounter a hazard or seismically significant lithological interface near the array we discuss the source characteristics from different phases of the coring and tunnelling processes, the construction site noise effects, signal propagation/attenuation and induced seismic phases.

EXPLODING THE PYROCLASTIC FLOW ENIGMA WITH LIFE-SCALABLE EXPERIMENTS

J. R. Evans¹ & G. Lube¹

¹Dept. of Geology, Massey University, Private Bag 11 222, Palmerston North.
jevans@mtu.edu

Researchers have rarely been able to take direct field measurements of pyroclastic flows given their destructive nature, creating a dangerous discontinuity in knowledge in the volcanology field. Thus far, experiments have only loosely followed pyroclastic flow processes by using synthetic materials, unheated conditions and small, laboratory scales, all of which, however, could detrimentally alter results. It is with this lack of knowledge in mind, that this research project is planned to investigate the theory that fine ash particles largely control gas-particle interactions within flows using quantitative analysis of scaled experiments with real volcanic materials and heated conditions.

A pyroclastic flow generator will be built and utilized for this experimentation, in which temperature and grain size distributions will be varied, while initial volume flux and initial particle concentration will be held constant to determine the effects of fine ash particle concentrations on overall pyroclastic flow dynamics. Within this generator, instrumentation will be placed in a minimally invasive manner to measure space- and time-dependent vertical profiles of particle concentration, particle velocity and gas velocity along the entire flow runout length and determine the spatial evolution of internal structure and particle/gas interaction modes within flows. In addition to experimental data, field samples will be collected, velocities of natural flows measured via RADAR and flow sizes determined via satellite imagery for validation of experimental parameters.

With further understanding of pyroclastic flows, scientists will be able to improve upon existing models of flows, thus augmenting the effectiveness of comprehensive volcanic models with which hazard maps and risk predictions are based. These improvements would ultimately allow for increased preparedness of at-risk populations and enhance volcanic hazard mitigation techniques.

CHARACTERIZING FAVOURABLE STRUCTURAL SETTINGS OF GEOTHERMAL RESERVOIRS IN EXTENSIONAL REGIONS: ENHANCING EXPLORATION STRATEGIES

James E. Faulds¹, Mark F. Coolbaugh² & Nicholas H. Hinz¹

¹Nevada Bureau of Mines & Geology, University of Nevada, Reno, Nevada, USA, 89557.

²Great Basin Center for Geothermal Energy, University of Nevada, Reno, Nevada, USA.

jfaulds@unr.edu

Exploration of geothermal systems is commonly hampered by the risk of unsuccessful drilling. A major problem in selecting well sites is that the favourable settings of known systems are generally not adequately characterized. This is particularly important in amagmatic regions, where faults are the dominant control on geothermal fluids and obvious magmatic heat sources are lacking.

To better characterize the structural controls on geothermal systems in extensional settings, we have analyzed numerous fields in the relatively amagmatic Basin and Range (USA) and Aegean (western Turkey) extensional provinces. Methods include detailed geologic mapping, structural analysis, gravity surveys, and studies of surficial geothermal features (e.g., travertine, sinter, springs, fumaroles). Our findings suggest that many fields occupy a) discrete steps in normal faults; b) intersections between normal and transverse oblique-slip faults; c) overlapping oppositely dipping normal fault zones, d) terminations of major normal faults, and e) transtensional pull-aparts. These settings are typically associated with steeply dipping faults, commonly involving subvertical conduits of highly fractured rock along Quaternary fault zones oriented approximately perpendicular to the least principal stress. General topographic features indicative of these settings include: 1) steps in range-fronts, 2) interbasinal highs, 3) series of relatively low, discontinuous ridges, and 4) lateral terminations of mountain ranges. Surficial features, such as tufa towers, travertine spring mounds, and sinter deposits, are also associated with many systems. These structural, topographic, and surficial features may indicate blind geothermal systems, which have no surface thermal waters or steam.

We have successfully applied our findings to exploration of several geothermal fields in the Basin and Range province, including Desert Peak, Desert Queen, Salt Wells, and Astor Pass. Further characterization is needed, however, of favourable structural settings and other critical parameters (e.g., geophysical and geochemical signatures) to substantially reduce the risks of geothermal exploration.

SALT MARSH FORAMINIFERAL PROXY RECORDS OF SEA-LEVEL RISE AT THREE SOUTH ISLAND LOCALITIES

B. O. Figueira^{1,2}, **B.W. Hayward**², **H.R. Grenfell**²

¹Dept. Of Geology, University of Auckland, Auckland, New Zealand .

²Geomarine Research, Auckland, New Zealand.

b.figueira@auckland.ac.nz

Salt marsh foraminifera produce valuable sea-level estimates and have been used in a number of North Atlantic studies. These estimates are in good agreement with 20th century tide-gauge and satellite observations, and can extend the sea-level record back beyond the 19th century and into the Holocene, serving as valuable 'proxies' when other data is not available. Little Southern Hemisphere foraminifera-based sea-level research has been published. Three areas, considered tectonically stable, were chosen from the South Island of New Zealand: Waikawa Harbour (Southland), Akaroa Harbour (Banks Peninsula), and Whanganui Inlet (NW Nelson). At all sites modern foraminiferal transect samples from across the salt marsh were analysed to provide modern analogue data for a tidal elevation-based transfer function. A preliminary age model was developed and used to calculate rates of sea-level rise in Waikawa Harbour, with rates of sea level rise of 0.3±0.4 mm/yr before 1880s, increasing to 3.5±0.4 mm/yr during the last century, with a total of 60cm of sea level rise during the past 600 years. These results are comparable to the study published from Pounaweia (Catlins, South Otago), which indicates that sea level rose slowly before 1900 (0.5±0.4 mm/yr), but during the 20th century increased to 2.8±0.5 mm/yr, with a total of 40cm of sea-level rise in the past 400 years. The other two study sites await the age model data, but the foraminiferal data indicates a 60cm of sea-level rise. Our aim is to compare South Pacific data with the Northern Hemisphere where there is debate as to whether there are accelerations or decelerations during the 19th and 20th centuries. This New Zealand input into a largely Northern Hemisphere debate is of critical importance in determining whether human-induced increases in greenhouse gases and consequent global warming are in any way responsible for modern rapid rates of sea-level rise.

MEGA-DEPOSITIONAL SEDIMENTARY EVENTS AS CHRONOSTRATIGRAPHIC MARKERS WITHIN DEEP- MARINE BASINS: THE WAITEMATA BASIN, NEW ZEALAND

C.T. Fildes¹, **L.J. Strachan**¹ & **W.D. Mccaffrey**²

¹School of Environment, Private Bag 92019, Auckland, New Zealand

²TRG, School of Earth and Environment, University of Leeds, Leeds, LS2 9JT, UK

c.fildes@auckland.ac.nz

Using mega-beds as chronostratigraphic markers is a key element of basin analysis. Mega-beds are characteristically basin-wide and laterally extensive. The aim of this study is to understand the geometry and architecture of the mega-beds to see if they can be used as a basin correlation tool. The Parnell Volcaniclastic Conglomerates (PVCs) are mega-beds observed within the Miocene Waitemata Basin. The mega-beds are a collection of distinctive 2 – 20m thick, coarse volcaniclastic beds that are interbedded with thin-medium (0.02 – 2 m) bedded sandstone and siltstone turbidites. The PVC's occur widely within the basin, with 100 or so occurrences in an area of 40 – 70km². The outcrops of Waiwera and Mahurangi East display three separate conglomerate mega-beds. Lateral correlations of these successions imply the background sedimentation is thinning to the north over 7 kms, indicating a broad lenticular geometry. These dimensions exceed the limits of most channelized settings. In the south (Waiwera) the intervening strata is coarser-grained, consists of more massive sand type lithofacies and there is evidence of increased amalgamation. The conglomerate beds at this location are also coarser-grained. The youngest conglomerate unit appears to thin to the north, however the two stratigraphically older conglomerate beds appear equal in thickness. These units display an increased amount of substrate entrainment and injection to the north. The conglomerate beds are laterally extensive and therefore suggest a sheet-like geometry. However the thinning of the succession and increased entrainment may suggest some of the conglomerates are channelized and demonstrates the heterogeneity of the system. Geochemistry and geochronology of the volcaniclastic clasts within the mega-beds will help to correlate the units on a large scale to fully understand their depositional setting and geometries.

COLLAPSE MECHANISMS IN OVERBURDEN ROCKS ABOVE ABANDONED UNDERGROUND MINE WORKINGS, STOCKTON PLATEAU

M. Fitzmaurice¹

¹Dept. of Geological Sciences, University of Canterbury, Private Bag 4800, Christchurch
matt.fitzmaurice@pg.canterbury.ac.nz

Abandoned mine workings on the Stockton Plateau present a health and safety hazard to mine personnel as Stockton mine expands into areas mined in the past by underground methods. The roof of the abandoned workings are, in some areas, collapsing (or have collapsed), with the voids migrating towards the surface. This becomes a hazard when mining equipment is operating on top of these voids as there is the potential for caving beneath the equipment. As such, the mechanisms of collapse need to be understood. This project is mainly focused on the Millerton Block, but with application to the wider Stockton Plateau.

The voids are generally not collapsing by way of 'classical subsidence', where the overburden collapses into the mined out section with an angle of draw of approximately 50° and creates bowl-shaped depression at the surface. The collapse is more reminiscent of chimney-type collapse, where successive joint-controlled blocks fall into the mined out section, causing the void to 'migrate' towards the surface. The size of the blocks is controlled by the sub-horizontal bedding of the overburden strata, and by orthogonal joint sets.

As a result of field investigations, including extensive laser scanning of voids, and detailed analysis on Vulcan software, three main types of collapse have been identified. Type 1 initiate from the initial excavation roof and extend upwards until a stable arch is formed, usually near the top of the coal seam or just above it. Type 2 form near the top of the coal seam and extends up into the overburden as successive slabs fall in, until a stable, stepped arch is formed. Type 3 is least understood and subject to further investigation. It forms beneath some steeply dipping defect which appears to prevent a stable arch forming.

CLIMATE AND ENVIRONMENT IN EARLY MIOCENE NEW ZEALAND: NEW EVIDENCE FROM AN OTAGO MAAR LAKE

B. Fox¹, **G. S. Wilson**², **D. E. Lee**¹, **A. R. Gorman**¹, **U. Kaulfuss**¹,
D. Jones¹

¹Dept. of Geology, University of Otago, PO Box 56, Dunedin
²Dept. of Marine Science, University of Otago, PO Box 56, Dunedin
bethany.fox@gmail.com

The Foulden Maar near Middlemarch, Otago, is infilled with a ~120 metre thick high-resolution diatomite succession. Palaeomagnetic measurements combined with pollen and radiometric dating suggest that the deposit represents ~100,000 years and spans the Mi-1 event.

Two drill cores covering the entire succession were retrieved in 2009. The upper ~60m of the diatomite is laminated on a millimetre to sub-millimetre scale, with white layers composed almost entirely of diatoms and sponge spicules and dark layers composed of organic matter and resting spores. White-dark couplets are interpreted to correspond to annual variations in diatom productivity and, indirectly, in climate. The lower ~60m is darker and contains a higher proportion of terrigenous material. Deformed beds and volcanogenic horizons increase in frequency with depth.

Magnetic susceptibility and remanence measurements of the upper part of the succession indicate a relatively uniform and proportionally minor ferromagnetic fraction with little influence from high-coercivity phases, implying uniform environmental conditions. Variation is mainly manifested in varying thickness of the white laminae. Spectral analysis reveals significant power at several frequency bands, ranging from decadal to millennial.

In the lower part of the succession, higher frequency (decadal) cycles are suppressed, although longer-term cycles are still present. Varves are thinner and more uniform in appearance, and the proportion of terrigenous material is higher. Variation is dominated by variations in allochthonous input rather than biological productivity, suggesting a colder, less stable environment.

SEISMIC CHARACTERISATION OF GAS HYDRATE SYSTEMS ASSOCIATED WITH ACTIVE MARGIN SEDIMENTS, HIKURANGI MARGIN, NEW ZEALAND

D.R.A.Fraser¹, A. R.Gorman² and I. A Pecher³

¹Dept. of Geology, University of Otago, PO Box 56, Dunedin.

²Dept. of Geology, University of Otago, PO Box 56, Dunedin.

³GNS Science, Lower Hutt, New Zealand
drafraser@gmail.com

The Pegasus sub-basin in the southern part of the larger East Coast Basin, is located in the zone of transition between the tectonic regimes of North Island subduction and South Island transpression. This region, is known to contain significant deposits of gas hydrates, as demonstrated by several multidisciplinary studies in the area since 2005.

These studies, based on the acquisition and analysis of seismic, heat flow, and controlled-source electromagnetic (CSEM) data, indicate that hydrates are primarily located beneath thrust ridges that may enable focussed fluid flow, and that the hydrates are associated with free gas. The host rock for the gas hydrates is suggested to be fractured mudstones and potentially, localized channel sands.

In late 2009 and early 2010, a new seismic dataset was acquired in the Pegasus sub-basin area by Crown Minerals. The survey conducted by the *M/V Bergen Resolution*, included approximately 3000 km of 2D seismic data in a region bounded by the Cook Strait to the west and the Chatham Rise to the south.

The seismic data were acquired using a 12-km-long streamer, providing a grid of data over an area of approximately 35,000 km². Water depths in the region ranged from approximately 500 to 3000 m.

Preliminary examination of shipboard stacks included identification of an 80 km-long Bottom-Simulating Reflection (BSR) on one line, as well as other features associated with the BSR that may indicate the presence of gas hydrates in zones of high concentration. Quantitative analysis of the data, including high-resolution velocity analysis, provides insight into the nature of interesting seismic features such as bright spots (high-amplitude anomalies) and flat spots (indicating potential fluid contacts). The analysis allows for the identification of targets for more detailed seismic investigation during a future survey planned for early 2011.

RUPTURE SCENARIOS FOR THE DARFIELD EARTHQUAKE

B. Fry¹ & R. Benites¹

¹GNS Science, 1 Fairway Drive, Avalon, Lower Hutt.

b.fry@gns.cri.nz

The Darfield earthquake is remarkable in that it was well captured with local strong-motion recordings. Eight stations recorded peak accelerations larger than 0.5g. The stations are close enough to the earthquake to record sufficiently high frequencies to allow detailed analyses of the spatial and temporal evolution of the rupture. We will first present the results of ongoing work to map the rupture front through time using a source scanning algorithm. We create a 3D model of the Canterbury plains by dividing the region into 0.5km cubic blocks. Time is discretised into 0.1s windows. For each time step, we generate a 'brightness' function for each block showing the relative likelihood of the block as a source of energy contained in the seismograms. Regions with the highest 'brightness' are likely sources for the rupture at each time step.

We synthesize the wavefield resulting from competing rupture scenarios to determine which is more likely to reproduce the measured wavefield. The fault plane of the main strike-slip event is discretised into a grid of 1000 squares representing 1km × 1km subfaults. Based on values of total displacement inverted from low-frequency teleseismic seismograms, we produce a slip history for the first 20s of the main rupture. The fault is embedded in a well-defined layered medium with soft-soil layers distributed from the free-surface to 1.9km depth. We compute synthetic seismograms for up to 2Hz at strong ground motion stations close to the fault for two cases: (1) a hypocenter corresponding to the first-wave onset on the strike-slip fault plane at 12 km depth, (2) a hypocenter 6km north of the fault trace and 22km depth. By comparing the results we show that the latter case produces seismograms that best fit the main features of the observed seismograms.

TSUNAMI THREATS: EVALUATION AND ADVICE

N.H Gale¹, K.R. Gledhill¹ & W.L. Power¹

¹GNS Science, PO Box 30368, Lower Hutt

n.gale@gns.cri.nz

The New Zealand GeoNet Project is an integrated real-time geological hazard monitoring and data collection system for tsunamis, earthquakes, volcanoes, and landslides affecting the country, run by GNS Science with funding from the New Zealand Earthquake Commission. As New Zealand's premier institution for Earth Science research, GNS Science is the scientific advisor to the Ministry of Civil Defence and Emergency Management (MCDEM) on all geological hazards that threaten populations and infrastructure. In this capacity, GNS Science has an on-call 24-7 duty officer who is responsible for locating all potentially felt earthquakes and evaluating both local and distant earthquakes in terms of their potential for tsunami generation. When an earthquake meets pre-defined criteria indicative of a potential tsunami threat to New Zealand's coasts, the Tsunami Experts Panel (TEP) is activated. The TEP is responsible for providing MCDEM with detailed information about the forecasted impact to the nation's coastlines. This includes providing estimates of tsunami travel times to the main population centres and anticipated locations of early arrival, assigning threat levels to the 43 coastal zones of New Zealand, and issuing an 'all-clear' after the event. The primary tools used in these evaluations are 1) the tsunami scenario database, 2) the historic tsunami database and 3) tsunami propagation models including webSIFT and COMCOT. Tsunami waves that arrive on the offshore and main islands of New Zealand are recorded on the New Zealand Tsunami Monitoring Network, which consists of real-time coastal pressure gauges at 17 stations. All tsunami data are distributed freely via GOES, SeedLink and the GeoNet website, www.geonet.org.nz, to facilitate emergency response and research.

TOWARDS A MODEL FOR HYPERPYCNAL FLOW INITIATION, BEHAVIOUR AND DEPOSITION

R. Gavey

National Oceanography Centre, University of Southampton, SO14 3ZH, UK.

Rachel.Gavey@vuw.ac.nz

A review of modern processes and systems, interpreted as portraying examples of hyperpycnal flow events, provides a link between case studies of an ancient system – the Pliocene Pissouri Basin, Cyprus, and a modern system – Taiwan.

Varying definitions of flow initiation and behaviour are applied in recent literature, some showing discord when compared to each other and to earlier work which laid the foundations for the understanding of hyperpycnal flows. It is therefore necessary to revisit the definition of hyperpycnal flow and the varying forcing factors in operation.

Through original data from ancient and modern study sites together with a comprehensive literature review, a model is proposed which links initiation of hyperpycnal flow with a range of forcing affects; seismic, climatic and anthropogenic. Flow behaviour, transformation and resultant deposit characteristics can all be related to this model, which aims to better evaluate hyperpycnal flows in order to better identify their presence in the stratigraphic record, and to aid projections of their occurrence in the future.

ENHANCED RECORD OF TEPHRA FALLOUT SINCE ~AD 232 REVEALED BY
CRYPTOTEPHRA STUDIES AT MOANATUATUA BOG NEAR HAMILTON,
AND IMPLICATIONS FOR VOLCANIC HAZARD ANALYSIS

Maria J. Gehrels¹, David J. Lowe², Rewi M. Newnham³, & Alan G. Hogg⁴

¹School Geogr., Earth & Environ. Sci., University of Plymouth, Plymouth, PL4 8AA, UK

²Dept of Earth & Ocean Sciences, University of Waikato, Private Bag 3105, Hamilton

³School Geog., Environ. & Earth Sci., Victoria Univ. Wellington, Box 600, Wellington

⁴Radiocarbon Dating Laboratory, University of Waikato, Private Bag 3105, Hamilton
d.lowe@waikato.ac.nz

Cryptotephra are fine-grained tephra-derived glass-shard or crystal concentrations, or both, preserved in sediment and not visible as layers to the naked eye (from the Greek word *kryptein*, 'to hide'). We have been studying cryptotephra in peat bogs and lake sediments in northern North Island to develop an enhanced stratigraphic record of ash-fall events since the deposition of Taupo tephra in 232 ± 5 AD (which provides a visible benchmark layer). In this paper we describe the identification of ten post-Taupo cryptotephra in Moanatuatua bog near Hamilton following the separation, enumeration, and analysis of colourless and brown glass shards from enclosing peat. The ten cryptotephra, none visible in the field, comprise one rhyolitic deposit (Kaharoa tephra 1314 ± 12 AD, erupted from Mt Tarawera) and nine intermediate deposits, eight being derived from Mt Ruapehu and one from Mt Ngauruhoe on the basis of EPMA of constituent glass and age modelling based on 15 ¹⁴C dates. No Egmont/Taranaki-derived glass shards were observed. The dacitic/andesitic cryptotephra include five pre-historic Mt Ruapehu eruptives of the Tufa Trig Formation, namely Tf4 (729 ± 151 AD), ?Tf5 (1160 ± 51 AD), Tf6 (1315 ± 63 AD), Tf8 (1635 ± 99 AD), and Tf14 (1667 ± 62 AD) together with ash-fall from three historic Mt Ruapehu eruptions in 1861, 1945, and June 1996 (Tf19), and ash-fall from the February 1975 Mt Ngauruhoe eruption.

These findings extend significantly the known geographic distributions of all six prehistoric eruptives and also confirm deposition of four 'diffuse' historic eruptives, most of which were barely perceptible as fall events in the region at the time. These occurrences are important also because most have not been included in previous volcanic hazard assessments, and the potential impacts of such fallout represent a significant threat both to urban and rural industries, and potentially human health.

THE 2010 M_w7.1 DARFIELD EARTHQUAKE RUPTURE AND
REGIONAL STRESS IN THE NORTHERN SOUTH ISLAND

F.C. Ghisetti¹ & R.H. Sibson²

¹Terrageologica, 55 Mansfield Ave., Christchurch, 8014.

²Dept. of Geology, University of Otago, PO Box 56, Dunedin, 9054.

francesca.ghisetti@terrageologica.com

E.M. Anderson (1905) proposed that where σ_2 is vertical, wrench faults should initiate on vertical planes at c. 30° to horizontal maximum compressive stress in accordance with the Coulomb shear failure criterion. This relationship may not hold for strike-slip faults with large finite displacements (because of block rotations about vertical axes), but appears to hold for low-displacement structures. Available data on regional stress in the northern South Island are sparse, but a reasonably consistent picture is emerging of a horizontal maximum compressive stress (σ_1) oriented WNW-ESE from inversion of focal mechanisms, geological structures, and wellbore breakouts. A compilation of such data suggests σ_1 oriented 115±5°. However, the vertical component of the stress tensor is less well constrained, given the spatial and temporal coexistence of steep reverse faults striking 000-020°, and sub-vertical right-lateral strike-slip faults trending 080-095°. Derivation of the regional stress regime is complicated by: (i) extensive reactivation of inherited normal faults; (ii) reactivation of terrane boundary discontinuities; and, (iii) comparative paucity of young slip vector data from exposed fault surfaces.

Long-period focal mechanisms for the September 2010 M7.1 Darfield earthquake yield a subvertical, dextral fault striking 086-099° in good agreement with the mapped surface trace which trends 085-090°. The subvertical fault thus lies at 25-35° to the inferred regional σ_1 , close to that expected for an ideal 'Andersonian' wrench fault. This implies either that the structure is comparatively new-formed in the contemporary stress field, or that there has been preferential reactivation of an unknown, pre-existing fault that is optimally oriented in the stress field. The inferred orientation of maximum compressive stress is also compatible with reverse faulting along the eastern range front of the Southern Alps. Improved definition of the regional stress field will facilitate hazard assessment from both recognised and unrecognised active faults through slip tendency analysis.

ERUPTION PROCESSES OF THE KELLYVILLE VOLCANIC COMPLEX

A. Gibson¹, R. M. Briggs¹, A. Pittari¹ & K. Nemeth²

¹Earth and Ocean Sciences, University of Waikato, Private Bag 3105 Hamilton

²Institute of Natural Resources, Massey University, Post Office Box 11 222
Palmerston North
acg16@waikato.ac.nz

The 1.48 Ma Kellyville volcanic complex in the South Auckland volcanic field consists of an early 45 m thick, 1.8 km diameter tuff ring and two later intra-tuff ring scoria cones, 45 m and 20 m high. A lake then formed in the tuff ring and deposited diatomite up to 8 m thick intercalated with pumice fall deposits in the lowest parts of the crater. Partial rim collapse is evident by small slump faults dipping towards the centre of the tuff ring, which has recently been breached on its western side by the Waikato River. Four facies types have been recognised in a 45 m thick tuff ring succession. The lowermost 4 m consists of a poorly sorted, massive to weakly bedded block and bomb facies (facies A). From 4-24 m, medium to thick beds (10-80 cm) of poorly sorted, massive fine lapilli to blocks and bombs (facies B) alternate with 60-150 cm thick packages of well sorted, cross-laminated coarse to fine ash (facies C). The upper 20 m consists of very well sorted, planar laminated coarse to fine ash (facies D). The succession represents an early vent clearing phase with abundant ballistic fallout, followed by more efficient magma-water interaction with surge-dominated processes. Juvenile material included ash, lapilli, and blocks and bombs of scoria tachylite and dense basalt. Lithic ash, lapilli and blocks within the tuff sequence changed from fossiliferous, calcareous sandstone (Mercer Sandstone) to calcareous siltstone (Koheroa Siltstone) as eruption excavation progressed, the former being the most likely aquifer for the phreatomagmatic eruption. The crystals included olivine, augite, plagioclase, Fe-Ti oxides, and xenocrysts of quartz and calcite. A scoria lapilli facies agglutinated at its base forms the two scoria cones. The Kellyville volcanic complex is an example of an initial phreatomagmatic eruption with progressive excavation of the basement and eventual exhaustion of an aquifer, followed by later purely magmatic activity.

THE DARFIELD EARTHQUAKE AND GEONET: SCIENCE TO PRACTICE

Ken Gledhill¹, Hugh Cowan² & David Coetzee³

¹GNS Science, PO Box 30368, Lower Hutt.

²Earthquake Commission, PO Box 790, Wellington.

³Ministry of Civil Defence and Emergency Management, Wellington.
k.gledhill@gns.cri.nz

The Darfield earthquake was the first geological event to have significant impact on the New Zealand community since the establishment of GeoNet in 2001. Within a few minutes of its occurrence at 4:36 am on Saturday 4 September 2010, the GeoNet website displayed the high levels of shaking experienced in the Canterbury region as reported by the GeoNet sensor network. Before a location had been established, the Ministry of Civil Defence & Emergency Management (MCDEM) was informed that a large, potentially destructive earthquake had occurred near Christchurch, New Zealand's second largest city. A short time later GeoNet reported a location (near Darfield) and a magnitude (originally 7.4, revised later to 7.1). Following a now long-standing arrangement GNS Science provided a liaison officer to work with MCDEM responders and representatives from other government and lifeline organisations in the National Crisis Management Centre (NCMC). This allowed for the seamless flow of scientific information for the national response.

The GeoNet sensor network provided data from hundreds of sites, 40 of which were within 50 km of the earthquake location. This is an internationally significant dataset, particularly of near-source strong ground motion. The maximum acceleration recorded was over 100% of gravity, with large readings throughout Christchurch city and the surrounding region. The GeoNet website was an important source of information throughout the event and the aftershock sequence. Heavy website load was experienced after larger aftershocks, and additional third party websites appeared using GeoNet feeds to present the information in novel ways, demonstrating the power of open data.

The response to the Darfield earthquake demonstrates the strength of the GeoNet concept and is an example of science contributing to an effective event response. It also highlights the importance of the close relationship between scientists and the emergency management community.

RE-EVALUATING FEED ZONE LOCATIONS IN A HIGH TEMPERATURE GEOTHERMAL SYSTEM BASED ON EVIDENCE FROM DEEP CONTINUOUSLY CORED WELLS

T. Glynn-Morris, P. Bixley, K. Brockbank, F. Sepulveda, R. Winmill, K. McLean
Contact Energy, Wairakei Power Station, Private Bag 2001, Taupo, NZ.
Trystan.Glynn-Morris@contactenergy.co.nz

One of the challenges the geothermal industry faces is understanding the characteristics of feed zones; the source of geothermal fluids in the wellbore. This is relevant for well targeting, understanding well decline, and reservoir modelling. Over the past two years Contact Energy has continuously cored 13 boreholes and monitoring wells in the Wairakei - Tauhara geothermal system as part of an extensive scientific programme aimed at investigating the cause of subsidence anomalies. One of the many scientific advantages coring has over conventional rotary drilling is the detailed structural and geological information contained in the core (and often lost in the cuttings). An investigation is being conducted on how feedzones, determined from completion test data, correlate with other measurements from the drilling process and core measurements. The following factors are being considered (a) fluid loss zones from drilling data, the (b) Rock-Quality Designation (RQD) and Recovery Factors from drill core (a proxy to fractures and poor material properties), the (c) lithological information and the (d) core photos. So far it has been observed that the location of feed zones does not necessarily coincide with simple models of fracture, formation, and fault-related permeability. A discussion is presented on how the factors correlate with some preliminary conclusions suggested.

GPR SURVEYS ACROSS ACTIVE FAULTS AROUND OKATAINA VOLCANIC CENTRE

D. Gomez-Ortiz¹, F. Martin-Gonzalez¹, P. Villamor², S. Woelz³ & N. Litchfield²
¹GNS Science, PO Box 30-3668, Lower Hutt.
²Dept. of Biology and Geology, University Rey Juan Carlos, C/ Tulipán s/n
28933 Mostoles, Spain.
³School of Geography, Environment and Earth Sciences, Victoria University, PO Box
600, Wellington.
P.Villamor@gns.cri.nz

GPR surveys across active faults around the Okataina Volcanic Centre (OVC) are undertaken to gain insights into rift extension rates and volcano-tectonic interactions. GPR is a non-destructive shallow geophysical technique that allows imaging the subsoil structure down to several metres depth. North of the OVC, the Manawahe Fault displays evidence for rupture associated with volcanic eruption, and rupture without association to volcanism. A long (430 m long) GPR transect, parallel to the eastern wall of a paleoseismic trench, was obtained to complement trench data. Three reflectors, corresponding to the top of the Rotoma unit, the base of the Rotorua unit and an undefined boundary below Rotorua unit, can be distinguished. The general geometry of the reflectors is slightly undulating and with a general dip to the NW of about 5° except to the north of the palaeoseismic trench where they are roughly horizontal. Apart from the main strand of the Manawahe fault, with a prominent topographic scarp, several minor faults without topographic expression can be detected in the GPR images from the vertical truncation of the reflectors. The fault displacement estimated from the GPR data allows us to understand both the fault slip rate, as well as, the interactions between fault rupture and volcanic eruptions by constraining the depth of Rotoma Tephra on the hanging wall. South of the OVC, we intend to obtain two full GPR transects across faults and non deformed areas of the Ngakuru graben, to assess fault and off-fault contribution to extension rates. Preliminary GPR profiles in this area show consistent reflectors correlating with the Taupo Tephra, Rotorua Tephra and the top of the alluvial sequence below the tephra cover. We expect to be able to assess comprehensive rift extension rates from these three chronological markers.

**QUATERNARY STRUCTURE, MORPHOLOGY, AND STRATIGRAPHY OF THE OTAGO
AND SOUTH CANTERBURY SHELVES FROM 20 YEARS OF HIGH-RESOLUTION
SEISMIC PROFILING INVESTIGATIONS**

A.R. Gorman¹, M.G. Hill^{2,1}, & A.R. Orpin³

¹Dept. of Geology, University of Otago, PO Box 56, Dunedin

²GNS Science, PO Box 30368, Lower Hutt

³NIWA, Private Bag 14901, Wellington

andrew.gorman@otago.ac.nz

The geological characteristics of the modern continental shelf along the southeastern coast of the South Island of New Zealand are controlled by several factors including: (1) variations in sediment supply from several major rivers and the currents that distribute the sediments along the coast, (2) the distribution of underlying basement terranes, which are orthogonal to the coastline here, (3) the overprinting of Tertiary volcanism on the shelf, and (4) active tectonics related to the Pacific - Australian plate boundary that lies parallel to and ~250 km NW. Due in part to shallow water depths, conventional marine seismic data do not image the sedimentary units of the shelf very well. However, high-frequency single-channel marine seismic surveys, conducted over the last 20 years aboard *R/V Munida* at the University of Otago, have investigated various aspects of: (1) the structural controls on the shelf, (2) the sedimentary history and stratigraphic relationships of the shelf, and (3) unique morphological features (e.g., submarine canyons and seafloor vent structures). We present results from six of these surveys that have imaged as much as 250 m of the uppermost shelf, enabling the interpretation of stratigraphic units, ancient erosional surfaces, active faults at depth, and subseafloor vent structures. We have found that regional geological structures (e.g., the Dunedin Volcano and Waihemo Fault) strongly control shelf development, and also have a profound effect on currents along the shelf. These currents, in turn, strongly affect sedimentation, canyon developments and modifications to the shelf structure (e.g., benches on the slope). Additionally, stratigraphic observations and images of lowstand hydrogeological systems on the shelf provide evidence for the strong role that sea level plays in shelf development.

**SEDIMENT DISPERSAL PATHWAYS AND TRANSPORT PROCESSES IN THE OFFSHORE
FIORDLAND REGION.**

Matthew Gosling¹, L.J. Strachan¹, P. Barnes², H. Bostock², H. Neil², B. Hayward

¹Geology Programme, School of Environment, University of Auckland

²National Institute of Water and Atmospheric Research (NIWA), Wellington

³Geomarine Research, 49 Swainston Road, St John's, Auckland

mgos006@aucklanduni.ac.nz

This study investigates sediment cores and shelf samples obtained from between <100 m and ~2000 m water depth off Fiordland, by the National Institute of Water and Atmospheric Research (NIWA), with the ultimate goal of constructing a model regarding dispersal pathways and transport processes from the shelf to the deep marine basins.

This poster will present sedimentological data used to establish transport processes and provenance of material within event deposits inside the cores. Laboratory techniques used in the core analysis include core logging, magnetic susceptibility, electrical resistivity, density, x-ray imaging, laser grain size, carbonate content, benthic foraminifera, visual mineralogy, x-ray diffraction, and radiocarbon dating. Preliminary results suggest the event beds consist of very coarse silts interbedded with normally graded fine sands with sharp boundaries at the base and top of each event. These deposits are interpreted as stacked turbidites with the coarse silt material interpreted as either the tail, or the result of finer grained or more dilute turbidity current events, with the added possibility of hemipelagic fallout. We interpret and discuss the spatial and temporal variation of sedimentary processes and dispersal from the event bed data, with comparison to the common turbidite emplacement models. Variation from the models will provide evidence of the likely triggering mechanisms and the processes which created the event beds.

MODELLING TWO-PHASE FLOW IN LARGE DIAMETER GEOTHERMAL PIPELINES

David Grace & Sadiq J. Zarrouk

Department of Engineering Science, University of Auckland, Private Bag 92019
Auckland,
agra165@aucklanduni.ac.nz

The strategy for the design and construction of the steam gathering system in geothermal power developments have evolved with time from individual wellhead separators to centralised separation plants to a single separation-flashing system near the power station. This new design strategy has resulted in longer and larger diameter two-phase pipelines.

The aim of this study is to review existing correlations two-phase pressure drop models then investigate and model two-phase flow pressure drop in large diameter geothermal pipelines.

Currently large two-phase pipelines are designed using experience and models based on correlated data for smaller diameter pipes. As a result the pipes maybe oversized or undersized for the required flow rates, which could result in undesirable flow regimes that can causes high pressure drop or limit the use of the pipe. Due to this we feel there is a need for reliable models that extends to large diameters, which will help in reducing capital costs, more predictable flow regimes and better pressure drop estimation.

For this investigation computational fluid dynamics (CFD) is used, which are based on the governing laws of two-phase flow and turbulence. The results are compared with data from the Wairakei steam field to validate and improve the accuracy of the simulation. The research is currently limited to straight-horizontal pipe sections, but will be extended to different fittings and pipe orientations in the future.

INTEGRATING SCIENCE INTO RESPONSE AND RECOVERY: SOME THOUGHTS FROM LOCAL GOVERNMENT

H.I. Grant¹

¹Environment Canterbury, PO Box 345, Christchurch.
helen.grant@ecan.govt.nz

Despite the lack of a formal structure around the science response after the 2010 Darfield (Canterbury) Earthquake and its relationship to CDEM, the science community and local government have worked cooperatively to provide the information required for response and ongoing recovery.

There are two significant audiences for science information: the community and central/local government decision makers. Providing simple information to the community about the earthquake and, more importantly, what was likely (and unlikely) to happen next, is essential. Information available on the internet and through the media about this event is voluminous and sometimes conflicting. We developed a simple factsheet addressing common questions being raised in the community. It is published under the Stronger Canterbury branding with the Canterbury CDEM Group logo, to be recognised as coming from a reputable source, and is updated weekly. There is scope to further develop science communications immediately after a large event, and for it to be better integrated into the welfare aspect of response and recovery.

For decision makers, as well as immediate needs around rebuilding decisions (mostly in the hands of insurers and central government), there are also needs around informing consent applications and plan changes already in progress. Ongoing investigations are also required to inform longer-term future development. This involves local government working closely with researchers and practitioners to avoid duplication of effort, to secure funding, to identify timelines for required outputs, and to develop ways of appropriately communicating findings to the community.

The 2010 Darfield (Canterbury) Earthquake has provided an excellent opportunity to identify gaps and put structures in place that will improve the way science is integrated into response and recovery (incorporating risk reduction) during future events in New Zealand.

CAN SURFACE ACTIVITY BE PROTECTED WITH DEVELOPMENT?

M. A. Grant

MAGAK, 208D Runciman Rd, RD2, Pukekohe 2677
mkgrant@farmside.co.nz

Recent consents and applications have featured protection of surface activity while a geothermal field is developed. Some idealised cases are considered, and the extent to which surface activity can be protected while a field is developed is discussed. Several different cases are distinguished with differing possibilities for mitigation.

HISTORICAL ACTIVITY AT TAUPO VOLCANO, NEW ZEALAND: A CONTRIBUTION TOWARD CALDERA UNREST MANAGEMENT

Sally Grant^{1,2}, **David Johnston**^{1,2}, **Gill Jolly**¹, **Vince Neall**³ & **Brad Scott**¹

¹Wairakei Research Centre, GNS Science, Private Bag 2000, Taupo.

²Joint Centre for Disaster Research, Massey University, PO Box 756, Wellington.

³Institute of Natural Resources, Massey University, Private Bag 11 222, Palmerston North.

s.grant@gns.cri.nz

The potential volcanic unrest which has been reported at or near Taupo caldera during historical times is identified and summarised. The information comes from an analysis of historical newspaper clippings, correspondence, relevant literature and scientific reports. Early results have identified new evidence of earthquake swarms in 1878, causing springs to become more active than usual; two weeks of constant earthquakes in 1880; and warm, sulphurous lake water in 1897. This adds to a magnitude six earthquake in 1895 which caused major damage, fissures, landslides and subsidence in the Taupo region; an earthquake swarm in 1922 lasting for up to six months and causing fault displacements, subsidence of up to 4m and self evacuations; high levels of anxiety and uncertainty due to an earthquake swarm in 1964-65; and uplift, fault rupturing and subsidence accompanied by earthquakes in 1983. New, more sensitive monitoring techniques identified uplift in 1996-9 at the centre of the lake; and most recently possible small inflation events in 2006-9, with an earthquake swarm in 2008. These may be indications of unrest, but do they indicate an impending eruption at the world's most productive caldera?

What will we do if an earthquake swarm strikes Taupo tonight, or next week's deformation data show a significant level of uplift? At what stage do the scientists change the volcanic alert level, making it official that there is a reawakening giant on our doorstep? How have more sensitive monitoring techniques impacted decisions? How is the inevitable economic impact reduced? When do emergency management officials evacuate Taupo? What happens if decisions are made too late?

This historical data analysis will contribute to my research which aims to discuss and resolve these issues using international case studies and decision making models, and by working with scientists and emergency managers on effective management of caldera unrest.

BASIN ANALYSIS IN THE TVZ, NEW ZEALAND: DEVELOPMENT OF THE TAUPO RIFT, IGNIMBRITE FLARE-UPS, AND PUNCTUATED RAPID SEDIMENT ACCUMULATION

**D.M. Gravelly¹, C.J.N. Wilson², J.V. Rowland³, G.S. Leonard⁴, D.C.H. Hikuroa⁵
& C. Scholz³**

¹Dept. Geological Sciences, Canterbury University, PB 4800, Christchurch.

²SGEES, Victoria University, PO Box 600, Wellington.

³School of Environment, Auckland University, PB 92019, Auckland.

⁴GNS Science, PO Box 30368, Lower Hutt.

⁵IESE, Auckland University, PB 92019, Auckland.

darren.gravelly@canterbury.ac.nz

The part of the on-shore Bay of Plenty that overlaps with the width of the modern day Northern Taupo Volcanic Zone (TVZ) holds important clues to understanding the volcano-tectonic evolution of the TVZ. In particular, stratigraphic studies and dating of tephra in Pleistocene sediment sequences behind Matata on the western side of the Whakatane Graben has revealed a westerly jump in the locus of the TVZ Rift at ~370 ka. This shift is closely coincident with and linked by us to the contraction of volcanic vent sites from Old to Young TVZ and the onset of a major flare-up in TVZ silicic volcanism. Tectonics has controlled the location of sedimentation within the Bay of Plenty. From ~700 ka to ~370 ka, there was a broad scale depocentre stretching from Maketu to Whakatane that shrank to its present width (Matata to Whakatane) at ~370 ka. Both before and after ~370 ka, small-scale (10's to 100's m wide) horst structures concentrated sedimentation into narrow fault bounded graben and half-graben structures, as also seen in offshore seismic profiles. Tectonics and sea level, however, had less effect on volume and rates of sedimentation than fluctuations in large-scale explosive TVZ volcanism. If sedimentation is a) localised by growth of faults within the overall Whakatane Graben, and b) controlled by episodes of voluminous TVZ silicic volcanism, then applying average sedimentation rates as a proxy for graben development may only provide a low-resolution picture of graben evolution. We infer that major readjustment of the Taupo Rift at ~370ka and the ~340ka to ~240ka TVZ flare-up of voluminous ignimbrite eruptions are linked. Further work will focus on constraining these major tectonic and volcanic events as part of the large-scale volcano-tectonic evolution of the TVZ.

METHOD OF OPERATING A REINJECTION WELL

Tony Gray

Geothermal Energy Solutions Ltd, 7 Beckside Close, RD4 Hamilton.

tony.ges@xtra.co.nz

A typical modern geothermal plant extracts geothermal fluid from a geothermal reservoir via a production well, takes heat from that fluid and returns the heat depleted fluid to the reservoir via an injection well.

All deep geothermal fluids contain dissolved solids, under conditions of elevated temperature and pressure. When heat and steam is extracted from the geothermal fluid, there is the possibility of depositing some of the dissolved species (particularly silica) in the plant, pipelines, reinjection wells or the reservoir near the reinjection wells.

By reducing the pH of the fluid to about 5.0 the rate of formation of colloidal silica is slowed. This means that the monomeric silica stays in solution, even when supersaturated (at lower temperature) for a period of time. The power plant efficiency can be improved, and more energy extracted for a given fluid extraction rate, by reinjecting at a lower temperature.

The time taken for pH modified brine to be disposed of in the reservoir is critical to the success of this plant design. This paper explores possible mechanisms for the deterioration of reservoir permeability, based on the geothermal fluid not being disposed of in sufficient time. It contemplates recirculation of fluid in a dead-leg at the bottom of the well and proposes methods to mitigate this effect.

ESTIMATION OF TECTONIC SUBSIDENCE IN THE NORTHERN SOUTH ISLAND USING FORAMINIFERAL PROXIES

H.R. Grenfell *, B.W. Hayward, A.T. Sabaa, J. Kay

Geomarine Research, 49 Swainston Rd, St Johns, Auckland

h.grenfell@geomarine.org.nz

Fossil foraminifera provide some of the most precise reconstructions of former Holocene sea levels, but are based on species with a narrow high tidal zonation. Low tidal-subtidal sediment is more commonly preserved and much more widespread than sequences containing high tidal salt marsh peat deposits. Recognition of former low tide levels, although lacking the precision of the tight high-tidal zones, allows investigation into possible Holocene tectonic displacements in the absence of preserved high-tidal sediment.

In this study we identify two foraminifera-based proxies for low-tide levels in sheltered harbour or estuarine mudflats. One proxy, similar to others used elsewhere, is the increasing relative abundance of two calcareous foraminifera which comprise >5% of the fauna below mean low water neap level in salinities >30 psu. The new proxy is based on the periodic occurrence of a wedge of low-salinity, low-pH surface water trapped in the heads of sheltered elongate bays. These conditions increase the relative abundance of intertidal, brackish, agglutinated foraminifera and promote the dissolution of calcareous-shelled foraminifera down to ~0.5 m below extreme low water spring level.

We use these two proxies, in association with the modern analogue technique, to estimate former sea level heights in four cores of Holocene sediment from two sites in the northern South Island of New Zealand. On the basis of these, we calculate a gradual subsidence rate of 0.55-1.05 m kyr⁻¹ over the last 4 kyr at Anakoha Bay in the northern Marlborough Sounds. The results provide independent evidence in support of long-held hypotheses favouring a recent subsidence origin for the deeply-drowned valley systems of the Marlborough Sounds. The record from Nelson Haven indicates that little, if any, uplift has occurred within the last 6 kyr across the westernmost fault strand of the Waimea-Flaxmore Fault system.

UPPER MANTLE HETEROGENEITY AND DEPTH-DEPENDENT ANISOTROPY IN THE WESTERN MEDITERRANEAN SUBDUCTION ZONES

S. Greve¹ & H. Paulssen¹

¹Utrecht University, PO Box 80021, Utrecht, The Netherlands.

greve@geo.uu.nl

The central Mediterranean subduction zone evolved in a complex dynamic process with a westward retreating trench. The openings of several basins, such as the Tyrrhenian Basin are coupled to the slab evolution. However, details of the process are still unclear. Further complexities of the subduction dynamics are caused by a series of slab windows in the Calabrian arc, as indicated by body wave tomography and complex pattern of magmatism.

Mantle anisotropy measurements provide a direct tool to investigate mantle dynamics and to measure strain in the mantle. But shear-wave splitting measurements for Italy show complicated pattern and their restricted depth resolution hinders detailed interpretation for 3D processes. Moreover, measurements are restricted to onshore. The transition of the anisotropic fast orientations in the Tyrrhenian Sea from the prevailing E-W on Sardinia to the complex pattern on mainland Italy is therefore still unknown.

Here, we apply a surface wave dispersion tomography with the aim to identify depth dependent azimuthal anisotropy for Italy and the Tyrrhenian Sea. We use data from various temporary and permanent seismic stations in Italy, Tunisia, Corsica and Sardinia to measure interstation fundamental mode Rayleigh wave phase velocities. The measurements are then used to obtain a shear wave velocity model and azimuthal anisotropic phase velocity maps. These results can complement teleseismic shear wave splitting measurements to provide a more sophisticated image of the 3D anisotropic structure of the Tyrrhenian Sea and Italy. This will help to improve our understanding of the dynamic evolution of the western Mediterranean subduction zone and the Calabrian arc.

OROCLINE DEVELOPMENT AND RELATED LITHOSPHERIC DELAMINATION IN THE IBERIAN ARMORICAN ARC

G. Gutiérrez-Alonso¹, J. Fernández-Suárez², A.B. Weil³, D. Pastor-Galán¹ & S.T. Johnston⁴

¹Universidad de Salamanca, Departamento de Geología, 37008, Salamanca, Spain

²Universidad Complutense de Madrid, Dept. de Petrología y Geoquímica, Spain

³Bryn Mawr College, Department of Geology, PA, USA

⁴University of Victoria, School of Earth & Ocean Sciences, BC, Canada
gabi@usal.es

The kinematic evolution and the timeframe for the development of the Ibero-Armorican Arc (West European Variscan Belt), as a bend of a previously more linear orogenic belt, has recently been constrained paleomagnetically as an orocline developed in the uppermost Carboniferous-lowermost Permian, between about 310 and 295 Ma, and it is considered to have been ultimately caused by the self-subduction of the Pangean global Plate. Given the large scale of this plate-scale structure, it is bound to have had a profound effect on the lithosphere and consequently the effects of the involvement of the lithosphere should be recognized in structures and geological features of different nature and at different scales developed coevally with the orocline.

New U-Pb zircon ages and Sm/Nd data from granitoid intrusions of western Iberia have yielded crystallization ages that significantly cluster around 307 Ma (ranging from ca. 309 to 297 Ma) in the outer arc of the orocline, whereas younger granitoid crystallization ages (ca 303-290 Ma) are found in the core of the orocline.

We interpret that, while the 307 Ma granitoids in the outer arc represent decompressive melting during the mechanical thinning of the mantle lithosphere below the outer arc during bending. Younger granitoid ages in the inner arc are interpreted to represent orocline triggered lithospheric delamination in the tectonically-thickened inner part of the orocline. Both processes resulted in the mantle replacement under the western sector of the European Variscan Belt.

³⁹Ar/⁴⁰Ar AGES OF VARISCAN SYN-OROCLINE STRIKE-SLIP SHEAR ZONES IN NORTHWESTERN IBERIA

G. Gutiérrez-Alonso¹ & E. González-Clavijo²

¹Dept. de Geología, Universidad de Salamanca, 37008, Salamanca.

²Instituto Geológico Minero de España, 37001, Azafranal 48, Salamanca.
e.clavijo@igme.es

One of the most striking large scale geological features in the NW of the Iberian Peninsula is the tightly curved segment, in plan view, of the Variscan orogen that is part of the Iberian-Armorican Arc. The European Variscan Belt is a piece of a mainly Carboniferous orogenic system including the Appalachians and Ouachitas, in North America; and the Mauritanides, in Northern Africa. Different evolutionary models have been proposed for this prominent curvature, but recent palaeomagnetic research points to the development of this oroclinal bending during the uppermost Carboniferous and earliest Permian. Some other geological features were traditionally attributed to a minor late-Variscan tectonic event; although they include some first order features: a) magmatism at orogenic-belt scale; b) development of low-P/high-T metamorphic belts; and c) growth of a complex pattern of sub-vertical strike-slip shear zones with related ore deposits (mainly Au and Sn-W). The age of some of these shear zones was interpreted to be between 315 and 300 Ma based on their field relations with magmatic bodies of known age. ³⁹Ar/⁴⁰Ar ages on muscovite syn-kinematic with the strike-slip deformation in 5 large scale shear-zones are presented in this study. These ages cluster around 307 Ma, constraining more tightly previous relative chronology. The synchronism of the shear zones with the palaeomagnetically constrained ages for the development of the orocline and the magmatism and ore occurrences suggests that this shear-zone system partially accommodated the orogenic bending at medium to high crustal levels, as can be deduced from their age and distribution.

VOLCANOLOGY, TUWHARETOA MYTHOLOGY AND HISTORY

John Ham

Tariao St, Tokaanu, Turangi.
hamtokaanu@xtra.co.nz

The New Zealand Royal Society have allowed me to look, listen and learn with some of our countries greatest geothermal minds and, equally as important, to do the same with Ngati Tuwharetoa Kuia and Koroua.

The aim was to uplift the profile of Science in my school by raising the interest of Science teaching with all teachers and Science learning with children.

The plan is to increase my knowledge and understanding of scientific geological processes by observing and working with GNS personnel at Wairakei, in strengthening my abilities in Geothermal field work.

Then, to incorporate this knowledge with Ngati Tuwharetoa matauranga, those relevant, orally related happenings in stories, songs and incantations that are related to volcanology.

To Tuwharetoa, matauranga is epitomised in the legacy of Ngatoroirangi, aquired at Taputapuatea and confirmed in his ascent of Tongariro. Matauranga is an idealistic, an inclusive worldview derived from an essential enviro-geographical intimacy. It's method is experiential observation and qualification.

Science is a system for the analysis and distillation of observable realty, in order to derive the critical knowledge as supported by available data. It is a system of know-what derived from a material, exclusive and reductionist world view. It's method is experiential observation and qualification,

Technology is the development of tools, processes and systems for practical application to meet human needs. It is a system of know-how that allows management and use of the environment. It's method is practise and utility.

Ngatoroirangi he toa, he tohunga, he rangatira an ancestral figurehead of Ngati Tuwharetoa, one of the great "scientists" of Maoridom, whose matauranga was unparalleled during the migration period.

We (like Ngatoroirangi) must use our matauranga based on our whakapapa to confirm our past (Whakapapa is the essence of Maori, the know-who of our being, the know-what and the know-why), consolidate our present (Whakapapa, the know-when and the know-which) and determine our future (Whakapapa, the know-where, the know-when, an epoch, the time is right, the time is now)

"Te Ahi Tamou : Rekindling the Fires" will make a difference in Science direction in my school, and impact on others in the area also. This has to ensure that the "fires" of Volcanology are better understood at the Ketetahi Springs and the Tokaanu geothermal system, and the "fires" of interest spark greater Science learning and matauranga.

THE 'DALY GAP' AND IMPLICATIONS FOR MAGMA DIFFERENTIATION IN COMPOSITE SHIELD VOLCANOES: A CASE STUDY FROM AKAROA VOLCANO, NEW ZEALAND

E. Hartung¹, B. Kennedy¹, C. Deering², A. Trent¹, J. Gane¹, R. Turnbull¹, S. Brown¹

¹Dept. of Geological Sciences, University of Canterbury, PO Box 4800, Christchurch

²Dept. of Earth and Space Sciences, University of Washington, Box 351310, Seattle, WA

eha63@uclive.ac.nz

The origin of compositional gaps in volcanic deposits has challenged petrologists since Daly's first observations at mid-ocean ridges. In the shield-forming Akaroa Volcano (9.6-8.6 Ma) of Banks Peninsula, New Zealand, a dramatic compositional gap exists in both eruptive and co-genetic intrusive products between basalt and trachyte, and between gabbro and syenite respectively. Rock compositions display mildly alkaline affinities ranging from olivine alkali basalt and hawaiite to trachyte. Intermediate compositions are absent (50-60 wt.% SiO₂). Previously, the formation of the more evolved trachyte has been ascribed to crustal melting. However, our analysis of new major and trace element data from minerals and bulk-rocks of this hy-normative intraplate alkalic suite provide evidence for an alternative model. Observed major and trace element trends in bulk-rocks can be reproduced by Rayleigh fractional crystallization from dry melts (<0.5 wt.% H₂O) at oxygen fugacities one unit below the quartz-fayalite-magnetite-buffer. The results of our MELTS models agree with experimental studies, and indicate a fractionation-generated compositional gap, where trachytic liquid has been extracted after the melt has reached a crystallinity of 65-70 %. The fractionated assemblage of clinopyroxene, olivine, plagioclase, magnetite and apatite is left in a cumulate residue. Calculated values of specific trace and minor elements (Sr, Cr, P) from a theoretical cumulate are consistent with measured concentrations from cumulate xenoliths. Compositional trends from individual mineral analysis are also supportive of fractional crystallization and illustrate a disrupted liquid-line-of-decent for each mineral phase. Olivine compositions progressively decrease in Mg concentration in basaltic melts and show high Fe concentration in trachytic melts. Clinopyroxene analyses also display higher Fe/Mg ratios in more evolved rocks. Ternary feldspar compositions shift from plagioclase in basalt to alkali feldspar in trachyte. In summary, our results indicate that these compositional gaps formed from punctuated melt extraction within an optimal crystal fraction window (60-70 % crystallinity).

SOIL CO₂ FLUX SURVEYS FOR GEOTHERMAL EXPLORATION – LESSONS LEARNED

M. Harvey & K. Alexander

Sinclair Knight Merz, Level 2 Carlaw Park, 12-16 Nichols Lane, Parnell, New Zealand.
mharvey@skm.co.nz

Soil CO₂ flux may indicate areas where degassing geothermal fluids are present in the near subsurface and their upflow is enhanced by permeable structures. Historically, soil CO₂ *concentration* surveys (% of CO₂ relative to other gases) have been used for geothermal exploration. However, it is more useful to understand the soil CO₂ *flux*, which is a measurement of gas flowing through a given cross-section per unit of time. This presentation provides some lessons learned from recent soil CO₂ flux surveys undertaken in Africa and the South Pacific by Sinclair Knight Merz for confidential clients. Our results show the technique has potential to locate permeable structures, but the technique is limited by survey size and orientation, vegetation and soil moisture content. Survey methods, and the effect of rainfall and topography on measured soil CO₂ flux are discussed.

HOLOCENE SUBSIDENCE RATES IN MARLBOROUGH SOUNDS

Bruce W. Hayward¹, Hugh R. Grenfell¹, Ashwaq T. Sabaa¹, Jon Kay¹, Rhiannon Daymond-King¹, Ursula Cochran²

¹Geomarine Research, 49 Swainston Rd, St Johns, Auckland

²GNS Science, PO Box 30 368, Lower Hutt
b.hayward@geomarine.org.nz

This paper provides evidence in support of a century-old hypothesis that the mountainous Marlborough Sounds region is subsiding. More recent hypotheses suggest that this may be a result of southward-migration of a slab of subducted Pacific Plate causing flexural downwarping of the overlying crust in the vicinity of the transition between subduction and strike-slip on the Pacific-Australian plate boundary. The proxy evidence for gradual Holocene subsidence comes from micropaleontological study of seven intertidal sediment cores from the inner Marlborough Sounds (at Havelock, Mahau Sound and Shakespeare Bay). Quantitative estimates (using Modern Analogue Technique) of former tidal elevations based on fossil foraminiferal faunas provide evidence of tectonic (not compaction-related) subsidence in all cores. Estimates of subsidence rates for individual cores vary within the range 0.2-2.4 m ka⁻¹. The wide variation within subsidence rate estimates are related to a combination of the accuracy limits of radiocarbon dates, elevation estimates, and particularly our poor knowledge of the New Zealand Holocene sea-level curve. The most consistent subsidence rate at all three sites for the mid-late Holocene (last 6-7 ka) is ~0.7-0.8 m ka⁻¹. This rate is consistent with the average subsidence rate in the adjacent 4 km-thick Wanganui sedimentary basin for the last 5 myr. Subsidence is inferred to have migrated southwards from the Wanganui Basin to impinge on the inner Marlborough Sounds in the mid-late Quaternary.

AUCKLAND'S 50th VOLCANO

Bruce W. Hayward¹, Jill A. Kenny¹, Roger High², Sian France³

¹Geomarine Research, 49 Swainston Rd, St Johns, Auckland

²Opus International Consultants, PO Box 5848, Auckland

³Beca Infrastructure Ltd, PO Box 6345, Auckland

b.hayward@geomarine.org.nz

In 1864, Hochstetter recognised 63 volcanoes in the Auckland Volcanic Field. Over the years this has been reduced, with Kermodé recognising 48 in the 1980s. A 49th was recognised by Smith in the 1990s when he split little Purchas Hill off from Mt Wellington on the basis of different chemistries. From the time of Hochstetter, Outhwaite Park on the crest of the Domain tuff ring, has been known to be a small scoria mound. Since Kermodé it has been lumped with the Domain Volcano as a small satellite cone with associated lava flow buried beneath Domain tuff.

Recent building construction and a water shortage have resulted in many new drillholes in the Domain-Grafton area. This new data allows us to recognise that a volcano of similar size and form to the Domain Volcano exists beneath the suburb of Grafton, mantled by 2-10 m of Domain tuff. Grafton Volcano's 500 m diameter explosion crater and partial tuff ring are recognisable in the topography. The crater is nearly filled with 50 m+ of basalt lava and has two vents – Outhwaite Park and another beneath Auckland Hospital.

We infer several years to decades between cessation of dry eruptions from Grafton Volcano and initiation of wet eruptions from the Domain next door. Initial phreatomagmatic Domain eruptions blasted away Grafton's eastern tuff ring. Later dry eruptions built a central scoria cone with basalt lava filling the Domain's explosion crater and overflowed the Carlton Gore Rd saddle. Lava withdrawal lowered the floor of the western part of Domain crater, which later accumulated 6-10 m of swamp peat. It is purely semantic whether one recognises Grafton Volcano as Auckland's 50th volcano separate from the Domain, or not.

PORTABLE BROADBAND SEISMOMETER DEPLOYMENT TO RECORD AFTERSHOCKS OF THE 4 SEPTEMBER 2010 M7.1 DARFIELD EARTHQUAKE

M. Henderson¹, C. Boese¹, M. Savage¹, B. Fry², C. Thurber³, K. Jacobs¹, S. Karalliyadda¹, E. Syracuse³, N. Lord³, R. Davy¹, K. Unglert¹, A. Carrizales¹, J. Eccles⁴, A. Zaino⁴, Z. Rawlinson¹, A. Seward², P. Malin⁴, A. Jolly², J. Townend¹, A. Shelley¹, A. Wech¹

1. Geophysical Institute, Victoria University of Wellington, New Zealand
2. GNS Science, New Zealand
3. Department of Geoscience, University of Wisconsin, Madison, USA
4. Institute of Earth Science and Engineering, University of Auckland, New Zealand

Mark.Henderson@vuw.ac.nz

The 4 September 2010 M7.1 Darfield earthquake is the most damaging earthquake to have struck New Zealand since the 1931 Napier Earthquake. We report on a multi-institutional and multi-national effort to record aftershocks to better understand the earthquake and its relationship to seismic hazard. In addition to the permanent Geonet stations and the short-period seismographs and strong motion seismographs deployed by GNS Science and discussed by Caroline Ashenden at this conference, we deployed a wider array of seismometers, which are still recording. This extra set of instruments consists of one short period and four broadband seismometers sourced from New Zealand stock and nine broadband seismometers from the US-based IRIS/PASSCAL Rapid Array Mobilization Program (RAMP). The seismometer locations were determined from experienced seismologists, supplemented with locations suggested from a new computer program. The program is being developed to determine the best place to put additional seismometers into existing arrays in order to best locate earthquakes. Most of the stations were placed to provide broad coverage suitable for earthquake location and tomography, but three broadband stations were placed on the fault trace to study fault-zone guided waves. The stations were all in place within two weeks after the earthquake, and will be in the field until the middle of December. The first download will be completed after the abstract deadline. We intend to show preliminary results from the deployment at the conference.

Support for this project is being provided by the Earthquake Commission, the University of Wisconsin and the US National Science Foundation.

**THE 2009-10 SAHKE EXPERIMENT: ACQUISITION AND PRELIMINARY RESULTS
ACROSS THE INTERSEISMICALLY LOCKED SOUTHERN HIKURANGI MARGIN,
NEW ZEALAND**

**S. Henrys¹, R. Sutherland¹, A. Seward¹, M. Henderson², T. Stern², M. Savage², J. Townend², K. Mochizuki³, H. Sato³, T. Iwasaki³, D. Barker¹, D. Bassett¹, R. Bell⁴,
& SAHKE Field Deployment Team**

¹ GNS Science, P.O. Box 30368, Lower Hutt 5040, New Zealand

² SGEES, Victoria University of Wellington, New Zealand

³ Earthquake Research Institute, University of Tokyo, Japan

⁴ Imperial College, London, UK.

s.henrys@gns.cri.nz

The passive and controlled source Seismic Array HiKurangi Experiment (SAHKE) project is designed to investigate the structure of the forearc and the physical parameters controlling locking at the Australian-Pacific subduction plate boundary beneath the southern North Island. SAHKE data were acquired between November 2009 and April 2010, in conjunction with a government funded marine seismic survey, and encompassed the full extent of the geodetically determined locked portion of the plate interface beneath Wellington. 480 km of marine multichannel seismic data were acquired on three SAHKE profiles across the convergent margin and recorded by 50 IRIS/PASSCAL short period sensors along one main onshore-offshore (two-sided) and three secondary (one-sided) transects. In addition, over 69000 offshore airgun sources were recorded by the 50 seismograph distributed SAHKE array and 20 permanent national network (GeoNet) stations during the MCS survey. The distributed and transect arrays also recorded a rich data set of more than 100 local earthquakes and 72 teleseismic events (> 6.0 Mw) over a 5 month period, including the 27 Feb 8.8 Mw Chile earthquake and aftershocks. Preliminary analysis shows strong arrivals interpreted as wide-angle reflections and converted waves from the subducting interface.

A KAITIAKI APPROACH TO RESOURCE DEVELOPMENT

D. Hikuroa¹, K. Morgan² & D. Gravelly³

¹Institute of Earth Science & Engineering, Uni. of Auckland, Priv. Bag 92019, Auckland.

²Dept. of Civil & Environmental Engineering, University of Auckland.

³Dept. of Geological Sciences, Uni. of Canterbury, Priv. Bag 4800, Christchurch
d.hikuroa@auckland.ac.nz

New Zealand faces some crucial decisions in the next few decades regarding Resources and Energy, and Maori are set to play an integral part. The key responsibility of Maori decision-makers is to act as kaitiaki (guardians), by implementing kaitiakitanga (guardianship) – a holistic approach to development that embodies an intergenerational approach, incorporates matauranga (Maori traditional knowledge) and more than economic return as the decision making priority.

Maori have a tradition of unity with the environment and have developed their own knowledge system, which they use to understand and interpret their own biophysical environments. The system of living as a part of and managing the environment constitute a key part of the cultural identity and social integrity of Maori. Additionally, indigenous knowledge embodies a wealth of wisdom and experience of ecosystems gained over millennia from direct observations, and transmitted – most often orally – over generations.

The concept of extracting resources from the Earth is not alien to Maori – indeed the purakau of Poutini, arguably the first geologic 'report' undertaken in New Zealand, documents the localities of important technology stone. Two key differences between traditional and contemporary resource use are scale of extraction and range of resources. Additionally, a Maori approach to development has its own ethos, ethics, set of principles and practices appropriate to an intergenerational sustainability strategy that incorporates the quadruple bottom-line of economic well-being, environmental well-being, social well-being and cultural well-being.

The key to realising New Zealand' Resource and Energy potential is a process that meets both legislative and kaitiakitanga requirements. The Mauri Model decision-making framework is based on the Resource Management Act and incorporates kaitiakitanga principles and is proving ideal for this purpose. This presentation will outline the key issues and present a case study demonstrating the immense utility of the Mauri Model to New Zealand.

A NEW ARCHAEOCETE (MAMMALIA: CETACEA) FROM NORTH CANTERBURY

Norton Hiller

Canterbury Museum, Rolleston Avenue, Christchurch
nhiller@canterburymuseum.com

The discovery of a partial maxilla with two teeth visible has led to the recovery of additional skull material and some anterior post-cranial bones from a small archaeocete cetacean. The specimen was found in a small exposure of the Ashley Mudstone at the foot of the cliff on the coast near the mouth of the Hurunui River in North Canterbury. Although next to a small slip, the rock containing the bones was deemed to be *in situ*.

The age of the specimen has not been determined precisely but the Ashley Mudstone in North Canterbury is believed to be Early to Mid-Eocene. If that is the case, then this specimen may represent the oldest archaeocete found to date in New Zealand.

The bones present indicate the specimen had a minimum overall length of about 65 cm. In addition to the maxilla, included in the assemblage are bones from the skull roof (frontals), bones from the ear region (periotics and tympanic bulla), cervical vertebrae, thoracic vertebrae, ribs and possible sternal elements. The sizes of the preserved bones suggest that perhaps the specimen is a juvenile.

Much preparation work remains before the specimen can be fully described and identified but from what can be seen at present, the bones appear to belong to a dorudontine close to, but not necessarily congeneric with, material described from the Waihao Greensand of South Canterbury as *Zygorhiza?* sp. by Kohler and Fordyce (1997). The cheek teeth present also resemble that of *Dorudon*-like Haast's archaeocete, also from the Waihao Greensand, which was described by Fordyce (1985).

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KINEMATIC SOURCE STUDY OF THE MW 7.1 DARFIELD EARTHQUAKE

C. Holden¹, B. Fry¹, J. Ristau¹ and M. Reyners¹

¹GNS Science, PO Box 30-368, Lower Hutt.
c.holden@gns.cri.nz

The Mw 7.1 Darfield earthquake has provided seismologists with a globally unprecedented set of near-source strong motion data (38 instruments within 50 km of the epicentre) from the GeoNet national strong motion network and the Canterbury Regional strong motion network.

We have inverted the 16 very near source data (less than 30 km epicentral distance) accelerograms to define the rupture sequence of the earthquake. The three-component data are filtered using a band pass filter from 0.001 to 0.2 Hz. We integrated the data once into velocity and then inverted the waveforms for slip vectors for individual patches on a discretized fault surface.

Our preliminary model suggests a rupture involving at least three fault planes. The rupture initiates on a steep thrust plane at the hypocentre location and depth of 11km. This is consistent with focal mechanism solutions obtained from analysis of first motions and results from regional moment tensor analysis. Ten to fifteen seconds later the main strike slip event begins, rupturing the surface with up to 4.5 m of right-lateral displacement, at the location of the mapped Greendale fault trace. This slip is consistent with the USGS and ERI focal mechanism solution for the mainshock. Eight seconds later a second strike slip event occurs at depth to the East and almost perpendicular to the Greendale fault trace. This last fault plane geometry is consistent with a clear linear trend of the aftershocks in this area, coincides with the location of an "asperity" incompatible with the main strike slip mechanism on the INSAR image. Adding the third rupture greatly improves the waveform fits of stations near Rolleston. However later arrivals at these particular sites can also be caused by guided surface waves. We are currently investigating this possibility. The individual event moments are Mw 6.8, Mw 6.9 and Mw 6.8 respectively.

Even though the waveform fit for these near source sites is very good, this analysis is still preliminary and this is ongoing research to better define the extent, depth and timing of the earthquake.

CALIBRATION OF THE NEW ZEALAND CRETACEOUS-CENOZOIC TIMESCALE TO GTS2004

Christopher J. Hollis, Alan G. Beu, James S. Crampton, Martin P. Crundwell, Hugh E.G. Morgans, J. Ian Raine, Craig M. Jones and Andrew Boyes
GNS Science, PO Box 30368, Lower Hutt, NZ
c.hollis@gns.cri.nz

The criteria used to establish the age ranges of New Zealand stages for Cretaceous-Cenozoic time have been reviewed and the ages have been calibrated to the 2004 International Geological Timescale (GTS2004, Gradstein et al. 2004), incorporating modifications introduced by Ogg et al. (2008) as well as recent biostratigraphic data from New Zealand studies. An updated version of the New Zealand Geological Timescale has been constructed using Timescale Creator vers. 4.10 (Ogg and Lugowski 2009). This updated New Zealand timescale is referred to as NZGTS 2010/1. For more details see Hollis et al. (2010).

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PALEOCLIMATE DATA/CLIMATE MODEL COMPARISONS FOR EARLY PALEOGENE NEW ZEALAND

Christopher J. Hollis¹, Kyle W.R. Taylor², Luke Handley², Richard D. Pancost², John Creech³, Joel Baker³, Elizabeth M. Kennedy¹, Erica M. Crouch¹, Hugh E.G. Morgans¹, Gary S. Wilson⁴, Pontus Lurcock⁴, Matthew Huber⁵ and Duncan Ackerley⁶

¹GNS Science, PO Box 30368, Lower Hutt, NZ

²Bristol Biogeochemistry Research Centre, University of Bristol, UK

³SGEES, Victoria University of Wellington, NZ

⁴Departments of Geology and Marine Sciences, Otago University, Dunedin, NZ

⁵Earth and Atmospheric Sciences Department, Purdue University, USA

⁶NIWA, Private Bag 14901, Wellington, NZ

c.hollis@gns.cri.nz

Multi-proxy (TEX₈₆, Mg/Ca, δ¹⁸O) records of sea and land temperature variation from late Paleocene to early Eocene, eastern South Island, suggest a more dramatic climate history for the region than the mild climatic changes indicated by previous oxygen isotope records, which are inferred to have been compromised by diagenesis. Sea floor and sea surface temperatures (SFTs and SSTs) increased by ~10°C from late Paleocene to early Eocene times. Late Paleocene (58-59 Ma) SSTs for Canterbury Basin and Campbell Plateau range from 18 to 23°C, consistent with coeval TEX₈₆ records from the south Tasman Sea. Late Paleocene SFTs of 2-8°C are equivalent to the present-day Deep Western Boundary Current. In contrast, the early Eocene of southeast New Zealand experienced truly tropical conditions. SST peaked at ~30°C at 50 Ma and declined to ~26°C by 48 Ma; SFT peaked at ~18°C at 50 Ma and declined to ~15°C by 48 Ma. A cooling step at 48.5 Ma corresponds to intensification in corrosive bottom water flow over the Campbell Plateau. SST estimates are consistent with coeval TEX₈₆-derived estimates from ODP site 1172, south Tasman Sea. Physiognomic analysis of early Eocene leaf fossil assemblages from eastern South Island suggests cooler subtropical climatic conditions – mean annual air temperature (MAAT) of 18-22°C (CLAMP) or 18-25°C (LMA) – but age control is poor. Both global and regional climate models under high CO₂ conditions (NCAR CCSM3, HadRM3p) suggest temperate conditions for New Zealand (SSTs of 15-20°C and MAAT of 14.5°C), which is consistent with Paleocene and later Eocene temperature estimates but not with Early Eocene temperatures. A tropical climate for early Eocene New Zealand implies that the role of ocean currents or other mechanisms of poleward heat transport or high-latitude heat retention are much greater under hyper-greenhouse conditions than is allowed for in the current generation of climate models.

HOW FAR DO TVZ TEPHRAS GO? DISTAL OCCURRENCE OF WHAKATANE TEPHRA AND THE POTENTIAL FOR CRYPTOTEPHRA STUDIES IN THE CHATHAM ISLANDS

K.A. Holt¹, **David J. Lowe**², **A.G. Hogg**³ & **R.C. Wallace**⁴

¹School of People, Env. and Planning, Massey University, PB 11222, Palmerston North

²Department of Earth and Ocean Sciences, University of Waikato, PB 3105, Hamilton

³Radiocarbon Dating Laboratory, University of Waikato, PB 3105, Hamilton

⁴Institute of Natural Resources, Massey University, PB 11222, Palmerston North
k.holt@massey.ac.nz

Macroscopic (visible) tephra layers derived from large-volume TVZ eruptions are not uncommon in sediments at distal locations (>~350 km from source) around NZ. However, visible layers derived from moderate- to small-volume eruptions (<<50 km³) are seldom encountered in similar distal settings. Their absence is generally attributed either to reworking or bioturbation (e.g. in marine sediments) or to a restricted distribution because of small volume, limited column height, and/or unfavourable meteorological conditions during an eruption. We report a newly-discovered occurrence of tephra fallout from a moderate-volume TVZ eruptive in a distal setting. Whakatane Tephra (WT) (5530 ± 60 cal. BP) occurs in peat deposits on Pitt Island, Chatham Islands, as a 5-mm-thick visible layer of dispersed very fine glass shards. Its correlation was facilitated via EPMA-derived major-element glass chemistry, supported by a ¹⁴C-age of 5455 ± 135 cal. BP (2σ) obtained on peat directly beneath and contiguous with the tephra. This occurrence of fallout from an eruption of volume ~11.3 km³ (DRE) in a very distal setting (~850 km downwind of source) illuminates the potential for further distal tephra and especially cryptotephra studies in NZ (cryptotephra are concentrations of glass shards and/or crystals not visible as a layer in the field). Although a rapidly growing field in the Northern Hemisphere, relatively few NZ-based cryptotephra studies have been published (Gehrels et al., 2006, 2008). This occurrence of WT in the Chatham Islands strongly implies that other moderate- to small-volume TVZ eruptives should also be present in peat and lake sediments if meteorological and preservation conditions have been favourable. A corollary is the potential for expanding correlations between palaeoenvironmental records from distal settings including the Chatham Islands. Such records have been targeted to improve understanding of short-term climate and environmental change in the NZ region since 30,000 yr ago in the NZ-INTIMATE project.

MIOCENE MICROBIALITES AS ARCHIVES OF BIOGEOCHEMICALLY DRIVEN METHANE-DERIVED AUTHIGENIC CARBONATE PRECIPITATION, EAST COAST BASIN, NEW ZEALAND

Steven D. Hood¹, **Kathleen A. Campbell**² & **Campbell S. Nelson**¹

¹Dept. of Earth & Ocean Sciences, University of Waikato, Private Bag 3105, Hamilton

²Dept. Of Geology, University of Auckland, Private Bag 92019, Auckland
s.hood@waikato.ac.nz

Miocene cold seep carbonates in onland East Coast Basin, North Island, host a variety of spectacular microbialite fabrics inferred to have formed from biogeochemical processes operating in ancient seafloor hydrocarbon seepage settings. A suite of advanced analytical techniques is elucidating the nature of these microbialite structures and their associated seepage conditions. Microbialites occur in a diagenetic spectrum from “pristine” aragonitic primary microstructures to neomorphically altered calcitic forms. Their development is best exemplified within carbonate-banded fracture/vug systems, or worm tube interiors that experienced high paleo-fluid flux. The microbialites appear as two distinct fabric types: (1) White, thin, “wispy”, (sub)mm, typically anastomosing microcrystalline laminae (stromatolite-like) that bifurcate around, or repetitively alternate with bands of fluorescent, hydrocarbon inclusion-bearing acicular botryoidal or isopachous fibrous aragonite cements. (2) Segregated, interconnected or coalesced patches of white, clotted microcrystalline carbonate (thrombolites) engulfed in radiating fibrous aragonite centres. While stromatolites and thrombolites would be familiar to many paleontologists as microbial in origin, the fibrous aragonite cements themselves also were, strictly speaking, microbially mediated, because both the microcrystalline carbonate and the fibrous cement bands/botryoids precipitated at or near the seabed by microbially driven anaerobic oxidation of methane (AOM). During AOM, archaea oxidise methane to produce excess porewater alkalinity in the zone of bacterial sulfate reduction, while free-living sulfide-oxidising mats and symbiotic chemosynthetic bacteria remove the sulfide produced to further enhance carbonate precipitation. Similar textures have been described from the modern convergent Hikurangi and Cascadia margins, and their diagenetic modifications may now be traced into the onshore New Zealand Miocene paleo-seep record. Lipid analysis provides additional evidence for archeal AOM and sulfate-reducing bacteria. Strongly depleted δ¹³C values (to -50‰ VPDB) are testament to the availability of hydrocarbon-bearing fluids to fuel chemosynthesis. Elemental analysis is underway to aid in a better understanding of the conditions leading to these diverse microbial fabrics.

HOT SPRINGS AT ORAKEI KORAKO, NEW ZEALAND: THE LAST 50 YEARS

T. Howe¹ & B. Y. Lynne¹

¹Institute of Earth Science and Engineering, University of Auckland, Private Bag 92019, Auckland.
t.howe@auckland.ac.nz

Hydrothermal surface features at Orakei Korako provide an opportunity to assess the long term variations in surface activity in an untapped geothermal field. Surface expressions of a geothermal system naturally vary with time and are sensitive to changes in the local hydrology. Surface activity at Orakei Korako straddles the Waikato River and in 1961 the construction of a hydro-electric dam at Ohakuri raised the water level of the Waikato River by 18 m, drowning hundreds of surface features.

Temperature, pH, flow rate, and water level measurements, as well as water chemistry analyses, documented between 1927 and 2009 from 25 surface features including hot springs, geysers, fumaroles, and steaming ground, were compiled and graphed to evaluate the long term changes in surface activity at Orakei Korako. Results revealed some features remain relatively stable with time while others are highly variable. Similarity/differences between hot spring behaviour were identified by examining long-term spring characteristics. For example, between 1995 and 1996 and again between 2003 and 2004, five hot springs (Diamond Geyser, Soda Fountain, Manganese Pool, Spring 772, and Spring 795) showed an identical hydrologic response in that they significantly decreased their water level by up to 2.5 meters.

Long term monitoring of the physical parameters of thermal features at Orakei Korako provides a base line of data that enabled the identification of surface features that behave unpredictably versus those that are relatively stable and show minimal change. Also, the monitoring of surface features at Orakei Korako located at different elevations and in different settings (i.e., along faults versus away from faults) provided information regarding subsurface connectivity. Tracking thermal activity in specific features over many years allowed the natural variation within an evolving geothermal field to be identified, as well as record the effect local hydrologic changes have on surface expressions.

ACIDIC CREEKS AND VOLCANIC GEOTHERMAL SYSTEMS

M.P.Hochstein

School of Environment and IESE, University of Auckland, Priv.Bag 92019, Auckland 1142
mp.hochstein@auckland.ac.nz

Acidic creeks have been found over the lower flanks and in the foothill region of active volcanoes in Sumatra (Sorikmerapi) and Flores (Inieri and Inielika). They are rare manifestations of volcanic geothermal systems and have been found until now at only three sites. Large volumes of hot, acidic (pH 2.5 to 2.9) sulphate water are discharged at exit temperatures between 42 and 75 deg C with flow rates between 200 and 400 kg/s. The creeks transfer between 25 and 35 MWth of anomalous heat (with reference to mean annual temperature).

The mineralisation of these acidic waters is low with 1.1 to 1.6 kg/s of dissolved solids (TDS) and c. 50 % SO₄ content. Isotope data are known for only one creek and plot on the meteoric water line. The concealed (upstream) flows seem to follow a cooling pattern similar to that of steam-heated, neutral pH bi-carbonate waters over high temperature geothermal prospects elsewhere in Indonesia. Wide-spread up-flow of steam and H₂S and condensation in heated groundwater are required to produce the large discharge and heat transfer rates. Locality and characteristics of the three known acidic creeks are listed below.

| Site | elev. (m) | volcano distance to summit | flow rate (kg/s) | T (deg C) | pH | TDS (g/kg) |
|-----------|-----------|----------------------------|------------------|-----------|-----|------------|
| Nage | 525 | Inieri c. 5 km | c. 200 | 75 | 2.6 | 1.6 |
| Mengeruda | 310 | Inielika c.13 km | c. 400 | 42 | 2.9 | 1.1 |
| Aek Milas | 650 | SorikM c. 5 km | c. 200 | 48 | 2.5 | 1.5 |

SELF-ORGANISED SYSTEMS AND ORE FORMATION: THE KEY TO SPATIALLY PREDICTIVE TARGETING?

J.M.A. Hronsky

Western Mining Services (Australia) Pty Ltd, 26/17 Prowse Street, West Perth, WA 6005, Australia and Centre for Exploration Targeting, School of Earth and Environment, University of Western Australia, Crawley, WA 6009, Australia, jon.hronsky@wesminllc.com

It is proposed that ore forming systems are examples of self-organized critical systems, in the sense of Bak et al (1987). Several lines of evidence support this hypothesis: the power-law size frequency distribution of mineral deposits; their fractal spatial distribution, their episodic, multicyclic nature and their spatial association with barriers to advective flow such as antiformal seals, and commonly periods of compressional deformation. This concept has very important implications for spatially-predictive mineral targeting, both at the regional and deposit scale. In particular, it emphasises that a local threshold barrier to fluid/magma flow is an absolutely essential ingredient for an ore forming system. This important practical implication of the SOC system model is not included within the current dominant paradigm for understanding mineral systems: that is source-trap-transport. In fact, it is probably this threshold barrier that provides the geological basis for the typical occurrence of mineral deposits within districts or camps. In many cases, it may be possible to develop proxies for the occurrence and spatial extent of these threshold barriers.

There are several other important practical implications of these ideas. One of the more important is that the existing paradigm for applying structural targeting in mineral exploration, which emphasizes zones of dilatancy related to fault kinematics and geometry, is incorrect. Instead ore fluids and magmas essentially create their own conduit zones between source and sink, utilising whatever structural architecture they encounter on their way. Another significant implication is that economic ore formation is likely to require very specific, and inevitably transient, anomalous geodynamic conditions.

MĀORI RESPONSIVENESS & RESILIENCE IN DISASTER MANAGEMENT

J. Hudson¹

¹Massey University, Private Bag 102904, North Shore Mail Centre, Auckland. J.T.Hudson@massey.ac.nz

In February 2004, several parts of New Zealand experienced serious flood disasters, with civil defence emergencies being declared in, for example, the Bay of Plenty and Manawatu regions. The disasters prompted co-ordinated responses from various sectors of the community, including Māori sectors.

This presentation discusses the findings and conclusions drawn from three research projects undertaken shortly after the flood event in the East Coast, Bay of Plenty and Manawatu regions. Each project explored the ways in which Māori communities and, particularly marae, responded during these events and examined the effectiveness of the distinctively Māori approaches adopted by these communities.

The research evinced unique attributes of resilience *within* Māori communities, in the context of the marae. It also revealed potential for development at the *interface* between these communities and the wider community response effort. The primary purpose of the presentation is to add to the evolving body of knowledge in the areas of Māori, indigenous and community resilience. Further, it seeks to contribute insight to developing emergency management policy and planning for both Māori and the wider community.

ESTIMATION OF PERMEABILITY OF THE ARTIFICIAL SUBSURFACE FRACTURE IN HIGASHI-HACHIMANTAI, IWATE, JAPAN, BY THE DYNAMICS OF FLUID IN A FRACTURE

S. Ito¹, K. Hayashi² & K. Nagano³

¹Akita Prefectural University, 015-0055, Yurihonjo, JAPAN.

²Institute of Fluid Science, Tohoku University, 980-8577, Sendai, JAPAN.

³Muroran Institute of Technology, 050-8585, Muroran, JAPAN.

sito@akita-pu.ac.jp

Estimation of permeability of a fracture in Higashi-Hachimantai geothermal model field in Iwate prefecture, Japan is presented. In this field, an artificial subsurface fracture exists. Two wells intersect this fracture. The distance between intersection points is around 7m. Many kinds of measurements using this artificial fracture were carried out. As one of those, measurements of guided wave along this fracture were carried out. In these guided wave measurements, an air gun was suspended near the one of intersection points between the fracture and the well which was used for hydraulic fracturing. A hydrophone was suspended at the other intersection point. During these measurements, the artificial fracture was pressurized to vary the interface conditions of the fracture, such as degree of contact. Data of guided wave in this fracture are used for estimation of permeability of this fracture. For estimation, numerical model of dynamics of fluid in a fracture are used. In this numerical model, a fracture is treated as a permeable layer. Shape of the fracture is square with a constant thickness. Stimulation point is set at the centre of the square. Measuring point is set at the point which is 7m apart from the centre point. For numerical analyses, a finite difference method is used. Estimations of permeability are carried out by comparing the spectra of field data with the spectra of numerical model. Permeability of this artificial fracture are estimated to be $3 \times 10^{-12} \sim 4 \times 10^{-10} \text{ m}^2$. These results agree with the results from transmissivity test in this field ($5 \times 10^{-12} \sim 5 \times 10^{-11} \text{ m}^2$).

CENOZOIC LIMESTONE ON AN OCEANIC VOLCANO: CHATHAM ISLANDS, NEW ZEALAND

N.P. James¹, C.S. Nelson², B. Jones³, H.J. Campbell⁴ & J. Titjen²

¹Geological Sciences, Queen's University, Kingston, Ontario K7L 3N6, Canada

²Earth & Ocean Sciences, University of Waikato, Private Bag 3105, Hamilton 3240, NZ

³Earth & Atmospheric Sciences, University of Alberta, Edmonton, Alberta T6G 2E3, Canada

⁴GNS Science, PO Box 30368, Lower Hutt 5040, New Zealand
c.nelson@waikato.ac.nz

The Chatham Islands, 850 km east of Christchurch in the SW Pacific, are the emergent part of a late Cretaceous-Cenozoic stratovolcano complex that is variably covered with limestones and fossiliferous tuffs. Most of these deposits accumulated in relatively shallow, high-energy, tidal current-influenced paleoenvironments with deposition punctuated by periods of deeper-water pelagic accumulation. Carbonate components in the neritic deposits are biogenic and dominated by molluscs and bryozoans - a heterozoan assemblage. The widespread Middle-Late Eocene Matangini Limestone contains local photozoan elements such as large benthic foraminifers (*Asterocyclina*) and calcareous green algae, reflecting the general Paleogene subtropical oceanographic setting. More localized Late Eocene-Oligocene deposits (Te One Limestone) as well as Pliocene carbonates (Onoua Limestone) are, however, wholly heterozoan and confirm a generally cooler-water oceanographic setting, similar to today. Early seafloor diagenesis is interpreted to have removed most aragonite components (gastropods and infaunal bivalves). Lack of aragonite resulted in the absence of interparticle calcite cementation during subaerial exposure such that most carbonates are friable or unlithified. Cementation is, however, present at nodular hardground-firmground caps to m-scale cycles. Such cements are microcrystalline isopachous circumgranular rinds of probable marine origin. The overall paleoenvironment of deposition is interpreted as mesotrophic, resulting partly from upwelling about the Chatham volcanic massif and partly from nutrient element delivery from the adjacent volcanic terrane and coeval volcanism. Biotic diversity in tuffs is 2 to 3 times that in limestones, supporting the notion of especially high nutrient availability during periods of volcanism. These mid-latitude deposits are strikingly different from their low-latitude, tropical, photozoan counterparts in the volcanic island-coral reef ecosystem. Groundwater seepage and fluvial runoff attenuate coral growth and promote microbial carbonate precipitation in these warm-water settings. By contrast, nutrients from the same sources feed the system in the Chatham Islands cool-water setting, promoting active heterozoan carbonate sedimentation.

**PETROLOGY OF PLIOCENE TE AUTE LIMESTONE FACIES, WAIROA DISTRICT,
NORTHERN HAWKE'S BAY**

Jared Jiang & Steven Hood

Dept. of Earth & Ocean Sciences, University of Waikato, Private Bag 3105, Hamilton
zj22@waikato.ac.nz

This project is studying the sedimentology and petrography of a shallow-marine, limestone-bearing succession (Mangaheia Group) within the Wairoa Syncline, northern Hawke's Bay. The primary focus is three Pliocene-aged cool-water "Te Aute type" limestone units (Early Opoitian Opoiti Limestone, Late Opoitian Whakapunake Limestone and Waipipian Tahaenui Limestone) that form locally spectacular and variably dipping outcrops. A suite of representative field/subsurface (exploration core) samples is undergoing laboratory analysis (standard, cathodoluminescence (CL) and SEM petrography, XRD, laser sizer, XRF, carbonate content). The massive Opoiti Limestone comprises poorly sorted, variably sandy (33-66% carbonate), barnacle and calcitic (epifaunal) bivalve debris (locally brachiopods) well-cemented by low-Mg calcite (LMC) (micro)sparite. They are sandy grainstones to skeletal arenites, and occasionally dolomite-bearing packstones. Localised calcite infilled biomoulds are testament to former aragonite skeletons. Opoiti Limestone grades up into mudstone before passing conformably into Whakapunake Limestone comprised of (cross) bedded and differentially cemented interbeds of fossiliferous- and more siliciclastic-rich facies. The limestones (up to 85% carbonate) are typically poorly sorted bivalve/barnacle grainstones cemented by variable amounts of fringe and later equant LMC (micro)spar. Fabrics are moderately open to tight with some conspicuous limonitised glauconite. An angular unconformity separates the Whakapunake Limestone from the overlying well-cemented flaggy Tahaenui Limestone, a bivalve/barnacle grainstone (50-80% carbonate) with some neomorphosed former aragonite skeletons and a moderately open fabric. Early formed dull luminescent isopachous fringing cements (host specific) precede variable pore occlusion by dirty LMC (micro)spar and/or micrite, sometimes including abundant zoned stoichiometric dolomite rhombohedra. Limestone formation was controlled by tectonic and glacioeustatically driven sea-level cycles along the margins of an active forearc basin under the influence of strong tidal flows. The calcitic dominated cool-water skeletal make-up of these limestones combined with shallow burial depths has resulted in rocks retaining significant macroporosity making them potential reservoir candidates as well as lime/hard rock resources.

**DISTINGUISHING BETWEEN SPATIAL AND TEMPORAL VARIATIONS IN ANISOTROPY
AT MOUNT RUAPEHU VOLCANO**

J. Johnson¹, M. Savage¹ & J. Townend¹

¹Institute of Geophysics, SGEES, Victoria University of Wellington.
jessica.johnson@vuw.ac.nz

Previous studies have reported that seismic anisotropy in the vicinity of Mount Ruapehu, determined via shear wave splitting (SWS) analysis, changes throughout the eruptive cycle. The anisotropy is thought to derive from stress in the crust aligning microcracks and creating an anisotropic medium. The polarisation of the fast quasi-shear wave, ϕ , is parallel to the maximum horizontal stress and the delay time between the two quasi-shear waves, δt , is proportional to the strength of the anisotropy and the length of the raypath in the anisotropic medium.

We have constructed a high-resolution reference map of anisotropy, using local crustal earthquakes that occurred in 2008 to determine the state of anisotropy at a time when there were no hypothesised temporal changes. To do this we first performed a two-dimensional slowness tomography on the δt values to map the regions of high anisotropy. We then used the resulting map of anisotropy strength to create weighting functions for the spatial averaging of ϕ .

The general trend of ϕ near Mount Ruapehu is NE-SW, which corresponds to the regional azimuth of maximum horizontal compressive stress determined from focal mechanism inversions and to ϕ inferred from SKS and Pn studies. To the west of Mount Ruapehu ϕ deviates from this trend, forming a semi-circular pattern.

In some regions the anisotropy is laterally uniform, while other regions display rapid spatial variations. We also observe variations in SWS parameters with back-azimuth and with depth, which emphasises the need to eliminate the possibility of spatial variations in the identification of temporally changing anisotropy. Using clusters of earthquakes and permanent seismic stations, we remove the uncertainty of spatial variation masquerading as temporal changes and look for robust temporal changes of SWS parameters with reference to our benchmark.

"IT'S TIME TO MOVE": IMPROVING THE EMERGENCY MANAGEMENT RESPONSE TO HAZARD WARNINGS

D.M. Johnston¹, E.E. Doyle¹, G.S. Leonard¹, D. Paton², B. Beets¹

1. Joint Centre for Disaster Research, Massey University/GNS Science, PO Box 756, Wellington. 2. School of Psychology, University of Tasmania
david.johnston@gns.cri.nz

Increasingly sophisticated networks of technological warning systems provide decision-makers with relevant and timely information to generate responses. However, these responses may be sub-optimal due to human and systems failures. Emergency management officers (EMOs) frequently have to make decisions with incomplete or inaccurate information derived from unfamiliar data. They do so under considerable time pressure and in rapidly evolving and complex situations involving atypical inter-agency circumstances. EMOs need to acquire information, render it meaningful, and make decisions that must accommodate a range of emergent hazard consequences. Under these circumstances, EMOs situational awareness, or the ability to use limited cues to make sense of complex hazard information, is critically important. Previous work has examined how situational awareness is used. However, the way this awareness develops in volunteer EMOs, who must respond to infrequent, evolving, and complex hazard events characterised by uncertainty and ambiguity, has received only limited attention. A key aim of our research is to develop a model of how human decision-makers interact with decision-support technologies in a hazard warning situation. Drawing from recent tsunami and weather events this presentation explores the weak links in current response processes and discusses ways to improve decision-making and responses in complex, rapidly evolving events.

BENT AND BENDING CONTINENTAL RIBBONS AND ARCS OF MELANESIA

S. T. Johnston

Earth & Ocean Sciences, University of Victoria, PO Box 3065 STN CSC, Victoria, BC, Canada V8W 3V6. stj@uvic.ca

I previously explained the geometry of continental and arc ribbons extending north northwest from the Northland Peninsula of New Zealand, including the d'Entrecasteaux orocline, as a product of oroclinal bending driven by an Upper Miocene to recent 60° counter clockwise rotation of the Vanuatu-New Hebridean (VNH) arc (Johnston, 2004). Implicit in the model was that map-view deformation, including orocline formation and opening of the North Fiji back-arc basin, was driven by rollback of the slab subducting north to east beneath the VNH arc. Roll back, however, provides no explanation of (1) why the VNH arc is pinned to the northwest (necessitating the counterclockwise rotation); (2) continuity of the trench dipping beneath the VNH arc through a 90° bend into the Hunter Fracture zone; and (3) coeval counter clockwise rotation of Fiji through ~135°. Perhaps more critical is that it requires that roll back, despite being the passive response to sinking of a negatively buoyant slab, explain buckling of a ribbon continent about a vertical axis of rotation. This seems unlikely, and begs the question "is rotation of the VNH arc itself the result of oroclinal bending?" Such a model explains rotation of the VNH arc and opening of the North Fiji basin as the product of southward flexure of a beam stretching through the VNH arc to the south, around a 90° bend into the Hunter Fracture zone and ending against the Fiji – Lau – South Fiji ridge. In this model, buckling of a series of interconnected lithospheric beams is balanced by subduction and basin formation, and the entire system is driven by northward translation away from Antarctica.

WHAT LIES BENEATH THE CANTERBURY PLAINS – A REFLECTION ON SEISMIC REFLECTIONS

R. Jongens¹, JR Pettinga², JK Campbell², DJA Barrell¹

¹GNS Science, Private Bag 1930, Dunedin 9054

²Dept. of Geological Sciences, University of Canterbury, Private Bag 4800, Christchurch
r.jongens@gns.cri.nz

The 2010 Darfield (Canterbury) Earthquake and freshly-expressed east-striking Greendale Fault have encouraged renewed scrutiny of existing hydrocarbon exploration seismic reflection data beneath the Canterbury Plains.

In 1998, Indo-Pacific Energy undertook reconnaissance seismic reflection surveys across the Canterbury Plains in search of oil/gas structural traps. Soon after, the Natural Hazards Research Centre, University of Canterbury, was commissioned to interpret the first reconnaissance surveys, and integrate them with surface geology and pre-existing subsurface data (reprocessed 1963 BP Shell Todd seismic surveys and four exploration wells). Follow-up seismic surveys in 1999 and 2000 led to the drilling of two exploration wells. Subsequently, the 1:250 000 scale QMAP Christchurch and QMAP Aoraki geological maps incorporated this subsurface information.

Seismic lines that cross the Greendale Fault are of poor quality, and it is unclear whether or not there is faulting at depth. South of the Selwyn River and north of the Waimakariri River, higher quality data reveal a distinct pattern of east- or southeast-striking normal faults bounding grabens or half-grabens. Offsets accumulated largely during the Late Cretaceous, but in the south, smaller offsets extend into the Neogene sequence. In the north, Late Cretaceous-Paleogene normal faulting is recorded under and along strike of the active, predominantly contractional, east-striking Ashley Fault, suggesting reactivation of a pre-existing structure. In contrast, northeast-striking, southeast-facing reverse Quaternary faults beneath the western and northern parts of the Plains, such as the Hororata and Springbank faults, show no indications of pre-late Cenozoic offsets. These reverse faults represent an expanding deformation front associated with the present plate boundary.

Evidence from both onshore and offshore seismic reflection data, as well as surface geology, indicates a pre-Late Cenozoic east-west structural grain. Despite a lack of interpretable seismic reflection data beneath the new Greendale Fault, the best working hypothesis is that the east-striking Greendale Fault is a reactivated structure of Late Cretaceous extensional origin.

FIELD INVESTIGATION OF LATERAL SPREADING IN CHRISTCHURCH AND KAIAPOI FOLLOWING THE CANTERBURY EARTHQUAKE, 4 SEPTEMBER, 2010

P. Kailey¹, M. Cubrinovski¹, K. Robinson¹ & J. Dykstra²

¹Dept. of Civil Engineering, University of Canterbury, Private Bag 4800, Christchurch

²Dept. of Geological Sciences, University of Canterbury, Private Bag 4800, Christchurch
jesse.dykstra@pg.canterbury.ac.nz

Following the magnitude 7.1 Canterbury earthquake, a lateral spreading site investigation was conducted in areas that exhibited obvious post-earthquake ground deformation. Areas of investigation included the township of Kaiapoi, located approximately 17 km north of Christchurch, and the Burwood, Avonside, and Bexley suburbs of Christchurch.

24 transects were completed perpendicular to the apparent direction of spreading. Wherever transects intersected extensional cracks, chainage and ground slope were measured using a laser rangefinder. Horizontal and vertical displacements at each crack were recorded. Crack lengths were traced using GPS. The GPS data was then overlaid on to a map of liquefaction features to derive an overall graphical representation of ground deformation.

Lengths of extension, as inferred by summing all the crack widths from each transect, ranged from 9 cm to 5.8 m. The amount of extension in many areas was not directly related to distance from the adjacent stream, suggesting that gradient and local ground conditions may have controlled the extent of ground deformation. Measurements of ground slope suggest that most lateral spreading occurred on relatively gentle gradients between 0 and 4 degrees.

Future work will investigate possible relationships between lateral spreading, local ground conditions, and the type and severity of related structural damage.

INVESTIGATIONS OF LOCAL SEISMIC SITE RESPONSE IN THE CHRISTCHURCH REGION FROM THE TEMPORARY QCN STRONG MOTION DEPLOYMENT

A.E. Kaiser¹, A.I. Chung², R.A. Benites¹, A.J. Haines³, E.S. Cochran⁴, J.F. Lawrence², C. Neighbours⁴, B. Fry¹, H. Brackley¹, A. Seward¹, GNS field team¹, Victoria University field team⁵

¹GNS Science, PO Box 30368, Lower Hutt.

²Dept. of Geophysics, Stanford University, California

³GNS Science, Private Bag 1930, Dunedin.

⁴Department of Earth Sciences, University of California, Riverside, California.

⁵Geophysical Institute, Victoria University of Wellington, PO Box 600, Wellington.
a.kaiser@gns.cri.nz

Following the September 4th 2010 Darfield earthquake, we deployed a network of low-cost accelerometers across the greater Christchurch urban area to complement existing Canterbury strong motion network stations. These instruments, deployed for the first time in New Zealand, are connected to the Quake-Catcher Network (QCN) based in California, and form part of the rapid earthquake response program to record aftershocks. The small 14-bit USB instruments are hosted by volunteers from the public and transmit data via their home internet connection, allowing a large amount of information to be collected at low cost.

The network of ~180 instruments spans a 60-km-wide region. In contrast to previous QCN deployments, the Christchurch array provides particularly dense coverage over a small urban area. Approximately 150 sensors are deployed within a 10-km radius of the central city. The dense network coverage will allow block-by-block analysis of variations in ground motion and local amplification effects arising from the local geology. We intend to analyse seismic response in terms of spectral ratios and peak ground accelerations for the QCN and Canterbury strong motion networks. The QCN results will be calibrated using the research-grade Canterbury strong ground motion stations and finally compared against local geotechnical information and observed patterns of earthquake damage. Here, we will describe the QCN deployment and present the resulting strong motion data and preliminary results.

THE LATE EOCENE – OLIGOCENE CHALLENGER RIFT SYSTEM AND THE RAPID TRANSITION TO CRUSTAL SHORTENING

P. J.J. Kamp¹ & K. P. Furlong²

¹ Department of Earth and Ocean Sciences, University of Waikato, Hamilton

² Department of Geosciences, Penn State University, USA
p.kamp@waikato.ac.nz

The case for a Late Eocene – Oligocene rift system through New Zealand was published 25 years ago (Kamp GSA Bull., 1986). It developed out of an earlier proposal for the Waiau and Te Anau basins (western Southland) as part of an aulacogen at the head of the Emerald Basin (Norris et al. J. Geol. Soc., 1978). The Challenger Rift System differed in that the zone of extension was viewed as New Zealand-wide through western Southland, Westland, Northwest Nelson and Taranaki.

Late Eocene – mid-Oligocene relative motion between the Australia and Pacific plates in the New Zealand area, determined from finite duration stage poles (e.g. Furlong & Kamp, Tectonophysics 2009), amounts to c. 150 of km of distributed late Paleogene extension across continental New Zealand between Canterbury and southern Taranaki Basin (in their reconstructed positions), with greater amounts of extension to the south. Between 29 and 26 Ma (mid to Late Oligocene) and from north to south, extension was supplanted by oblique crustal shortening driven by a marked change (from NW-SE to NE-SW) in the direction of relative Australia-Pacific plate motion. Crustal shortening since 26 Ma has substantially structurally overprinted the evidence for the earlier extension.

In working to understand the stratigraphic and structural architecture of New Zealand's sedimentary basins, it is useful to think in terms of their location and age with respect to the L. Eocene – mid-Oligocene zone of distributed continental extension, the subsequent rapid and systematic change to crustal shortening (continent-continent collision), the duration and magnitude of which depends upon location, followed by a change to ocean-continent convergence, which has affected North Island and Fiordland, and is progressing in northern South Island.

SPATIAL AND DEPTH EXTENT OF ANISOTROPY IN SOUTH ISLAND, NEW ZEALAND

S. Karalliyadda¹, M. Savage¹ and Tim Stern¹

¹School of Earth Sciences, Victoria University of Wellington, PO Box 600, Wellington.
karallsapt@myvuw.ac.nz

We use local S phases recorded in the South Island (SI), New Zealand for the period of 2004-2010 to constrain the seismic anisotropy in the crust and the upper mantle. Shear wave splitting measurements that are calculated on all the GeoNet stations and four temporary deployments in SI reveal both laterally and depth varying anisotropy associated with regional tectonics. Apparent changes in both delay times and fast directions with depth in Northern South Island (NSI) suggest misaligned anisotropic fabrics at different depths. Large delay times (> 0.35 s) recorded above earthquakes at 30 – 70 km depths in the western Central South Island (CSI) imply the existence of localized anisotropic zone. Approximately E-W oriented fast directions examined at the stations in eastern northern and central SI appear to be mainly controlled by the regional stress in shallow depths. Further examination of these splitting parameters with respect to back azimuth, incidence angle, surface structural geology and regional stress patterns will allow us to fully characterize the anisotropy in SI and to delineate the deformation mechanisms involved with the subduction tectonics along the plate boundary.

REINJECTION INTO LIQUID-DOMINATED TWO-PHASE GEOTHERMAL SYSTEMS

Eylem Kaya and Michael J. O'Sullivan

Department of Engineering Science, University of Auckland, Private Bag 92019,
Auckland, New Zealand
e.kaya@auckland.ac.nz

A 3D numerical model of the Wairakei-Tauhara field is used to investigate the effect of reinjection on liquid-dominated two-phase geothermal systems. Wairakei-Tauhara is an interesting case study as it has been operated with no reinjection for most of its lifetime. Several scenarios are run with the model to test what would have happened if a different reinjection strategy had been followed. The impacts of different rates of outfield and infield reinjection on production enthalpy, reservoir pressure and temperature, recharge conditions and surface features are investigated. Our modelling results show that infield reinjection suppresses boiling and decreases energy production due to the decline in production enthalpy. Since pressure is maintained by cold reinjection, natural hot water recharge to the system is also suppressed. Low levels of infield reinjection (25% of the separated water) results in low level of thermal degradation and does not cause a significant pressure drawdown. Therefore this scenario appears to be a good infield reinjection strategy.

If the reinjection zone is close to the surface features a significant decline or disappearance of surface features occurs. If production is carried out without reinjection, the flow of chloride water from the deep aquifers to the surface features decreases with time and the ground surface tends to become steam heated. Reinjection supports the flow of chloride water to the surface features, but at a lower temperature than in the natural state.

The Erua earthquake swarm and seismic anisotropy in the Ruapehu region

B. Keats, M. Savage & J. Turner

Institute of Geophysics, Victoria University of Wellington
brookkeats@gmail.com

Mount Ruapehu is the largest active volcano in New Zealand and has erupted multiple times over the last few decades, the most significant being the 1995-96 eruptions. In this project seismicity generated from earthquakes in the Erua earthquake swarm, located about 15 km to the west of the summit, will be used to study temporal changes in seismic anisotropy in the region. Miller & Savage (2001) and Gerst & Savage (2004) suggested that seismic anisotropy changes throughout the eruptive cycle due to changes in the local stress field and proposed using these variations as an eruption forecasting tool. Spatial variations in anisotropy can be misinterpreted as temporal variations and these studies used local earthquakes of all back azimuths within 100 km of the volcano. Using a cluster of earthquakes as a source of seismicity eliminates this uncertainty.

The results varied from station to station but at FWVZ, the station with data covering the longest time period, we observe a significant shift in fast direction (ϕ) from 2004 to 2005 and shift back to its original orientation in late 2007. Two small eruption events occurred on the 4th October 2006 and the 25th of September 2007 so these changes could be due to volcanic activity influencing the local stress field, which can overprint the regional maximum horizontal stress field.

The results confirm that temporal changes at Mount Ruapehu are a reality and not due to spatial variations in the seismic source and indicate that the technique of monitoring anisotropy as an eruption forecasting tool holds potential.

EVIDENCE FOR A FRACTURE DOMINATED HYDROTHERMAL SYSTEM AT ST. GEORGE'S HILL, MONTSERRAT

C. L. Kenedi & G. Ryan

Institute of Earth Science and Engineering, Univ. of Auckland, 58 Symonds St,
Auckland
katelk@auckland.ac.nz

Geophysical and geological studies indicate that a permeable network of fractures is located under St. George's Hill (SGH), Montserrat. The fracture network originates from a mesh of intersecting large and small extensional faults. The network hosts a vigorous hydrothermal circulation system that has led to physical alterations of the local rocks and that may hold promise for sustainable energy applications.

SGH is an uplifted block of secondary volcanoclastic deposits. The uplift occurred along an east-southeast trending fault zone that dominates the width of southern Montserrat, the Belham Valley fault (BVF). Marine seismic reflection data indicate that the BVF continues offshore, dipping steeply north to at least 2 km depth. At SGH, evidence suggests the BVF intersects with another fault. The secondary fault has been observed in two ways, geological field mapping and a magnetotelluric (MT) study. The MT results suggest that areas of low resistivity extend west from SGH, along the BVF, with a conjugate fracture system toward the northeast. Fault intersections are thought to cause increased fracturing, facilitating hydrothermal circulation. Further evidence for a local fracture network is repeated earthquake swarms under SGH, at depths between 2 - 4 km (Miller et al., 2010). The hydrothermal system is also indicated by P-wave tomography data, which show a west-dipping low velocity zone under SGH between ~ 2 - 4 km depth (Shalev et al., 2010). The large low velocity zone is likely alteration from hydrothermal fluids. Evidence of large-scale and local hydrothermal alteration, and its location at a fault intersection including at least one large, deep fault, suggests St. George's Hill is a site of significant hydrothermal activity related to a tectonically driven fracture network.

Miller, V., et al., 2010, *Geophys. Res. Lett.*, 37, L00E21, doi:10.1029/2010GL043997
Shalev, E., et al., 2010, *Geophys. Res. Lett.*, 37, L00E17, doi:10.1029/2010GL042498

TIME-AND TEMPERATURE-DEPENDENT CONDUIT WALL POROSITY: A KEY CONTROL ON DEGASSING AND EXPLOSIVITY AT TARAWERA VOLCANO.

B.M. Kennedy¹, **A.M. Jellinek**², **J.K. Russell**², **A.R.L. Nichols**³, **N. Vigouroux**⁴

¹Geological Sciences, University of Canterbury, Private Bag 4800, Christchurch, 8140.

²Dept EOS, UBC, 6339 Stores Road, Vancouver, BC, Canada V6T 1Z4.

³IFREE, JAMSTEC, 2-15 Natsushima-cho, Yokosuka, Kanagawa 237-0061, Japan.

⁴Dept. ES, Simon Fraser University, Burnaby, British Columbia, Canada.

Ben.kennedy@canterbury.ac.nz

The permeability of volcanic conduit walls can govern eruption explosivity. During each eruption, reheating by ascending magma modifies the porosity, permeability and H₂O content of the conduit wall rocks. We investigate whether the unusual explosivity of the 1886 basaltic eruption at Tarawera volcano is related to the heating of the rhyolitic rocks, through which it erupted. We heat cores of perlitic rhyolite to 300 °C–1200 °C for 30 min to 3 days at atmospheric pressure. We characterize time- and temperature - dependent variations through analyses of SEM images, connected and isolated porosity, and water content. We identify four textural/outgassing regimes: Regime 1 ($T \leq 800$ °C, $t \leq 2$ h), with negligible textural changes and a significant loss of meteoric water (1.4–0.72 wt.% H₂O); Regime 2 ($800 \leq T \leq 1100$ °C, $t \leq 6$ h), with cracking and vesicle growth and a 5–10% increase in connected porosity; Regime 3 ($800 \leq T \leq 1200$ °C, $t \geq 30$ min), with healed cracks, coalesced and collapsed vesicles, and overall reduced porosity; and Regime 4 ($T \geq 1200$ °C, $t > 30$ min), with a collapse of all connected porosity. These regimes are governed by the temperature of the event relative to the glass transition temperature and the time scale of the event relative to a critical relaxation time for structural failure of the melt. We identify a quantitative transition from predominantly brittle behavior such as cracking, to viscous processes including crack healing and vesicle collapse. Applied to the 1886 basalt eruption at Tarawera, we show that progressive heat transfer ultimately reduced the open porosity and permeability of the conduit walls, thereby partially sealing the conduit. We argue that this mechanism was an underlying reason for the exceptional explosivity of the 1886 eruption. We further suggest that textural changes associated with reheating could explain some of the cyclic deformation and degassing observed at many lava domes preceding eruptions.

REGIONAL FAULTING IN AUCKLAND – A CONSEQUENCE OF ALLOCHTHON “NUDGING” AND REMOBILISED BLOCK FAULTING

J.A. Kenny, J.M. Lindsay¹ & **T. M. Howe**¹

¹Institute of Earth Science and Engineering, University of Auckland

jill.kenny@xtra.co.nz

Auckland’s early Miocene Waitemata Group sediments were uplifted and eroded (Les Kermode’s “late Miocene” peneplain surface) and subsequently buried by post-Miocene sediment and products from the Auckland Volcanic Field.

Recent information, obtained largely through the DEVORA project borehole database from holes drilled through post-Miocene material, has facilitated an appreciation of buried segments of this Waitemata Group “peneplain”. Height variations of both exposed and concealed portions of the paleo-surface suggest faults with a pattern of NNW and ENE trends offsetting a series of arcuate ridges.

Arcuate asymmetric ridges fan out southwards and south-westwards for more than 30 km across Auckland from the Silverdale-Albany area – the topographic expression of catastrophic sub-seafloor slope failures of the mid Waitemata Group sedimentary pile, “nudged” by, and incorporated into, the toe of the southward-migrating Northland Allochthon in the early Miocene.

Arcuate faults are truncated by ENE- and NNW-trending block faults. The ENE-trending faults may be related to post-early Miocene horst and graben features in the south Manukau and Franklin areas (e.g., Wiri, Karaka and Papakura Faults) and to the splay faults mapped off Auckland’s west coast. North- to NNW-trending normal faults are the most easily traceable disruptions to the paleo-surface and are therefore likely to be the most recent. Most are down-thrown to the west and are consistent with middle to late Miocene regional normal faults, such as the Wairoa, Drury and Waikopua Faults.

Some boreholes penetrated the greywacke basement of Auckland. A tentative diagram of the greywacke paleo-surface demonstrates that block faulting, especially trending NNW and up-thrown to the east, had begun before Waitemata Group “peneplanation”. Subsequent remobilisation of these faults has up-thrown segments in the far east of the region, where greywacke and oldest Waitemata sediments are now exposed.

Further investigations may yield important insights into the evolution of the Auckland Volcanic Field.

DEM-BASED METHODOLOGY OF SCORIA CONE PARAMETERIZATION IN THE SOUTHERN VOLCANIC ZONE OF TENERIFE (SPAIN) AND AN IMPLICATION TO OTHER MONOGENETIC VOLCANIC FIELDS: JEJU ISLAND (KOREA) AND AUCKLAND (NEW ZEALAND)

G. Kereszturi^{1,2,3}, F.J. Dóniz-Páez⁴, C. Guillen⁵, K. Németh¹, G. Jordan², S.J. Cronin¹ & Y.K. Sohn⁶

¹ Volcanic Risk Solutions, CS-INR, Massey University, PO Box 11 222, Palmerston North, ² Geological Institute of Hungary, Stefánia út 14, H-1143, Budapest, Hungary, ³ Dept. of Geology and Mineral Deposits, University of Miskolc, Hungary, ⁴ Dept. of Geography, Iriarte College in Tourism, University of La Laguna, Puerto de la Cruz, Tenerife, Spain, ⁵ Cabildo de Tenerife, Güímar, Spain, ⁶ Dept. of Earth and Environmental Sciences, Gyeongsang National University, Jinju 660-701, South Korea, kereszturi_g@yahoo.com

Monogenetic scoria cones can generate one of the most common volcanic hazards on the Earth in spite of their small sizes. They occur either upon the flanks of larger, polygenetic volcanoes or in relatively flat volcanic fields. The future volcanic activity can be predicted on the basis of the temporal and spatial distribution of past volcanic activity. The estimation of the relative ages of scoria cones based on their present morphometry can thus provide essential information for better characterization of the past and future activity of a volcanic field.

From the methodological point of view, cones' slope angle calculated from only 3 morphometrical parameters, including the cone height (H_{co}), cone width (W_{co}) and crater diameter (W_{cr}), is one of the most important 'age-indicator'. However, these formula-based methods are non resistant to the morphometric irregularities caused by the diversity of eruption mechanisms or post-eruptive modifications (e.g. erosion).

In this study, we introduce a new methodology that gives more reliable estimation of slope angles using Digital Elevation Models. Our primary aim is to estimate better the limits and pitfalls of morphometry-based dating using the scoria cones of Southern Volcanic Zone in Tenerife (Spain) formed during the last 1 Ma. The shape of these cones is very diverse from the gentle sloped, tuff ring-like architecture to the steep sloped cones. Furthermore, there are several field evidences of migrating eruption loci resulting in volcanic chains with multiple craters and/or breached cones. The variation in morphometry is probably derived from the variation of basal inclination of the prevolcanic surface and the eruption mechanism. We intend to examine the possibility of using the same method in other volcanic fields in different tectonic and topographic conditions, for example in Auckland (New Zealand) and Jeju Island (Korea).

MAORI KNOWLEDGE AND EXTREME ENVIRONMENTAL DISTURBANCE

D. King

Te Kuwaha o Taihoro Nukurangi, NIWA, Priv. Bag 99940, Auckland 1149, NZ
d.king@niwa.co.nz

Tsunami research is in its infancy in Aotearoa/New Zealand - with much of the work conducted to date based on random site selection and morphological guesswork. The importance of these early developments in palaeo-tsunami discovery is undeniable but there remain many questions and ambiguities about the timing, source and magnitude of such events. This presentation builds upon previous work which argued that the knowledge and experience contained within Māori oral histories and traditions (*pūrākau*) is a valuable and neglected area of information about past catastrophic events in Aotearoa/New Zealand. Here we will map *pūrākau* Māori that reference and/or relate likely experience with tsunami and/or storm surge, and explore the geographical significance and complementarity of these events. Consideration will also be given to the research context, the limitations and lessons learnt through this work, and the potential contributions of this 'new' information to tsunami research and natural hazards science in Aotearoa/New Zealand.

SITE CHARACTERISATION OF THE WHATAROA VALLEY FOR THE DEEP ALPINE FAULT DRILLING PROJECT, WEST COAST, NEW ZEALAND

A. Klahn^{1*}, M. Quigley¹, B. Duffy¹, G. De Pascale¹, T. Davies¹

¹Dept. of Geology, University of Canterbury, Private Bag 4800, Christchurch.

*apk18@uclive.ac.nz

The Alpine Fault in western South Island ruptures every 300±100 years in large magnitude (~7.9) earthquakes and presents a major seismic hazard to New Zealand. The Deep Alpine Fault Drilling Project (DFDP) aims to drill, sample, and monitor the Alpine Fault in order to investigate the processes of earthquake genesis, rock deformation, and fault gouge formation for a tectonically active fault late in the seismic cycle. Rapid dextral reverse movements and exhumation rates on the central section of the Alpine Fault at Whataroa Valley make this a geologically favourable setting to drill and sample fault rocks at depth that can be correlated with surface exposures. However, the suitability of the site for stationing a drill rig also depends upon practical issues such as the engineering geological characteristics of the proposed site (e.g., strength of soils, depth to bedrock, road access), possible geohazards (e.g., co-seismic shaking, flooding, landsliding), and drilling logistics (e.g., location of fault at depth relative to drill hole trajectory). We discuss the results of recent geological, geophysical, and geomorphic investigations of the Whataroa Valley drill site in order to provide a framework for proposed future DFDP operations. Specifically, we present digital GPS topographic maps to compliment recently acquired LiDAR data, shallow seismic geophysical results that reveal the subsurface geology and depth to bedrock, geomorphic and hazard maps, and favoured sites for drill rig location and access routes.

PLANKTIC FORAMINIFERA-BASED SEA SURFACE TEMPERATURE ESTIMATES AND LATE QUATERNARY OCEANOGRAPHY OFF NEW ZEALAND'S WEST COAST

Andrew Kolodziej¹, Bruce Hayward², Martin Crundwell³, George Scott³ & Michael Hannah¹

¹SGEES, Victoria University of Wellington, Gate 7, Kelburn Parade, Wellington

²Geomarine Research, 49 Swainston Road, St Johns, Auckland

³Institute of Geological and Nuclear Sciences, PO Box 30 368, Lower Hutt
andy.kolodziej@gmail.com

Planktic foraminiferal assemblages were used to investigate the paleoceanography of the Eastern Tasman Sea over the last 480 kyrs (Marine Isotope Stages 12-1). One hundred and sixty-two faunas have been assembled from Marion Dufresne piston core MD06-2986 (~43° S. off New Zealand's west coast, 1477 m water depth). Faunal changes through the last five glacial-interglacial cycles are used to track surface water mass movement. Modern Analogue Technique (MAT) and an Artificial Neural Network (ANN) were used to estimate past sea surface temperatures (SST) based on the foraminiferal census counts data. SSTs show that MIS 12 was the longest, sustained cold period, while the coldest temperature was recorded in MIS 5d (~8° C). Interglacials MIS 11 and 5e are the two warmest stages of the record, with SSTs reaching ~18.5° C, about ~2° C warmer than present day.

Contrary to either the western Tasman Sea or offshore eastern New Zealand, the eastern Tasman Sea has been fairly isolated from any major influx of subpolar or subtropical species carried in with surface water from either high or low latitude sources. Subtropical species' abundance is low (average ~0.6%) and only prominent during peak interglacials. Subantarctic species' abundance is low (average ~5.1%), but significant, particularly in glacial periods. Comparison of faunal and SST_{ANN} data along with ratios of *Nq. pachyderma*:*Nq. incompta* (previously referred to as coiling ratios of *Nq. pachyderma*) and a productivity proxy suggest that the STF migrated northwards towards the site in all glacial periods, and may have moved over the site in MIS 12 and possibly MIS 5d.

GRAVITY ANOMALIES AND GEOID UNDULATIONS ON CALDERAS IN TAUPO VOLCANIC ZONE

Masao Komazawa¹, Mituhiko Sugihara¹ & Brad Scott²

¹Geological Survey of Japan, AIST, PO Box 3058567, Tsukuba

²IGNS Wairakei Research Centre, Private Bag 2000, Taupo
komazawa-m@aist.go.jp

Large surface area of a caldera is often occupied by lakes or sea. Gravity measurements are difficult and expensive to make at sea or on lakes. However, measurements of geoid undulations, which are related to gravity anomalies, are easy to make over water surface. An efficient method of mapping geoid undulations is to make a continuous kinematic GPS survey on a lake or a bay. It can be made with only two GPS receivers and a small boat. We made three lake-bourne GPS measurements and 302 land gravity measurements in Taupo Volcanic Zone in 1996. Recently we re-processed the land gravity data using SRTM (90mDEM) data. Several parts of caldera boundaries and/or faults are observed more clearly. We also re-analyzed the lake-bourne GPS data. A gravity anomaly map was derived from both the geoid undulations on the caldera lakes and the free-air anomalies around the lake using LSC method. We succeeded in evaluating geoid undulations of Lake Taupo based on the surface ship GPS data in the wavelength range of 10-30 km. The shorter wavelength geoid undulations, which have not been examined yet, are important to investigate geological structure under the lake. We have ever detected the undulations whose wavelength is a few kilometers at calderas in Japan. Undulations of wavelength of several kilometers can be detectable in calderas in Taupo Volcanic Zone. We must select proper wavelength components and the integral constant to fix the final solution, which will be compared with the free-air anomalies based on the latest land gravity data of the area.

AN INTEGRATED SEISMIC AND GRAVITY INVESTIGATION OF THE ALPINE FAULT AT HAAST

A. Kovács & A. R. Gorman

Dept. of Geology, University of Otago, PO Box 56, Dunedin

kovad091@student.otago.ac.nz

The Alpine Fault is one of the major transpressional structures on Earth, yet its behaviour during a large earthquake has yet to be directly observed. Over its >470 km length it accommodates two-thirds to three-quarters of the 35 - 38 mm/yr oblique plate motion between the Pacific and Australian plates. Dextral strike-slip motion is estimated at 23.1 ± 0.8 mm/yr and the perpendicular is estimated at 5.9 mm/yr. Scarps of earlier Alpine Fault ruptures are readily identifiable. The previous paleoseismic work does not provide any direct evidence for the structure of the fault in the subsurface, which is needed to assess earthquake hazard along the Pacific-Australian plate boundary here.

In January 2009, two seismic reflection profiles and associated gravity surveys were collected along the coastal plain of southern Westland adjacent to the Haast and Turnbull River valleys to provide higher-resolution images of the Alpine Fault at depth. The results of the seismic profile and gravity survey at Haast are presented here. The geophysical transect cover ~4 km and is orientated perpendicular to the Alpine Fault. The line extends inland as far as possible (i.e., until limited by the extreme topography of the Southern Alps) in order to maximise the coverage of the hanging wall. Due to the rugged topography and temperate rainforest vegetation of the Southern Alps and West Coast of the South Island, suitable locations for collecting seismic reflection and detailed gravity data across the Alpine Fault are rare. The combination of gravity and seismic data enables the development of a subsurface model that supports a steeply-dipping Alpine Fault cutting through a thick section of coastal sediments overlying a strongly-glaciated basement. Our results provide information that will help characterise the type of fault motion that will occur on the Alpine Fault during a future earthquake.

TEMPORAL VARIATION OF SEISMIC ANISOTROPY AT OKMOK VOLCANO (ALASKA)

Sofia-Katerina Kufner¹, Martha Savage¹, Jessica Johnson¹

¹ Victoria University of Wellington, Box 600, Wellington, 6140.

Sofia_Kufner@gmx.de

Volcanic eruptions in the Aleutian region provide a hazard potential. Okmok volcano is historically the most active volcano in this region. We use shear wave splitting analysis to examine variations in seismic properties prior to and after the eruption of Okmok in 2008. This study examines a possible relation between temporal changes in seismic anisotropy and volcanic eruptions. Magma movement beneath a volcano can influence the state of stress in the crust. The induced stress changes favor the alignment of crustal cracks and can cause seismic anisotropy. Shear waves, traveling through an anisotropic medium, split into a fast and a slow component perpendicular to each other. The direction of these two components (ϕ) as well as the delay time (dt) between the components can change with time. These changes can be connected to volcanic eruptions. Examination of shallow earthquakes associated with the 2008 Okmok eruption has shown some temporal change in shear wave splitting before and after the onset of the eruption. But those changes could also be affected by spatial variation of earthquake location, which are in turn caused by magma movement. By looking at regional earthquakes, which are unaffected by shallow magma movement, we will get an image of stress variation. We have applied shear wave splitting analysis to waveforms of regional earthquakes from 2004 to 2010. Prior to the eruption, ϕ show mainly north–south orientation. After the 2008 eruption, ϕ rotated to become radial to the caldera. These observations suggest a local stress change that was caused by magma intrusion prior to the volcanic eruption. Further study will include the examination of deeper events which are located nearer to Okmok.

THE GREAT MARLBOROUGH CONGLOMERATE: REALLY MORE AWESOME THAN GREAT

T.E. Laird¹, K.N. Bassett & J.D. Bradshaw

¹Dept. of Geological Sciences, University of Canterbury, Prvt Bag 4800

Christchurch 8140

tamsin.laird@pg.canterbury.ac.nz

The Great Marlborough Conglomerate is a poorly sorted conglomerate with granule to boulder-sized clasts >10m in diameter. The composition, size and variety of the clasts suggest a series of debris flows deposited into background sedimentation of calcareous grey silty mud. The depositional setting changes somewhat throughout the formation between near shore and beach. The Great Marlborough Conglomerate is dated as mid to Late Miocene in age and outcrops ~40km north of Kaikoura. Changes in clast composition demonstrate pulses of uplift in the Kaikoura Orogeny during the Miocene.

Provenance of the clasts shows that the conglomerate is Torlesse-dominated, particularly in the south. The north shows more limestone while parts of the middle display more volcanics. The megaclasts are mostly limestone, though in the north large clasts of all types are found. The volcanic clasts found across the region are from three different sources identified by their geochemistry: Cretaceous Gridiron, Cretaceous Lookout and Oligocene Cookson Formations. The limestone is derived from both Amuri and Mead Hill Formations based on microfossil data and the presence or absence of chert. The minor siltstone and sandstone clasts are of intrabasinal origin.

The clast types and changes in provenance of the conglomerate from south to north indicate more than one pulse in the Kaikoura Orogeny and demonstrate that the Orogeny began in this region after the deposition of the Amuri in the Late Oligocene. The inclusion of large megaclasts shows proximity to source, particularly in the northern area; the limited large clasts found in the south are much more weathered. The presence of the limestone and sandstone intraclasts shows that part of a Late Cretaceous-Cenozoic basin was being uplifted and provided sediment for the Great Marlborough Conglomerate, while also giving a date of at least Late Oligocene for the unroofing.

**PALEO-TSUNAMI RECORD AND TSUNAMI HAZARD
IN WALLIS AND FUTUNA**

**Geoffroy Lamarche¹, James Goff³, Bernard Pelletier², Emily Lane¹ and
Sébastien Delaux¹**

¹: NIWA, Private Bag 14-901, Wellington, 6241, g.lamarche@niwa.co.nz

²: Institut de Recherche pour le Développement, Nouméa, New Caledonia

³: Australian Tsunami Research Centre, Uni. New South Wales, Sydney 2052,
Australia

Paleo-tsunami and tsunami hazard research from Futuna island, in the Wallis and Futuna archipelago Futuna includes 1) sedimentological and archeological studies of trenches; 2) a survey of the impact of the 2009 South Pacific Tsunami (SPT) undertaken immediately after the event and 3) numerical modelling of tsunami propagation and inundation on the islands.

Two palaeotsunamis dated 1860-2000BP and c.470BP were identified from sediment analysis, foraminiferal and radiocarbon dating and archaeological data associated with occupations that immediately underlie the deposits associated with both palaeotsunamis. A local earthquake in 1993 also generated a local tsunami and oral tradition suggest a destructive wave that may correlate to the c.470 event.

The 29 September 2009 SPT reached the islands of Futuna and Alofi, 650 km to the west of its origin, at ca. 7.10 am on 30 Sep. local time. Run-up heights and inundation distances were measured at 41 sites around the islands. The worst impact were 4.5 m run-up; 95 m inundation; 3.8 m flow depth, not necessarily at the same location. The tsunami arrived as a drawdown of water and was followed by two positive waves of similar amplitude, ca. 4 minutes apart. Damage was mainly limited to salt-burnt vegetation and sediments deposited at the coast. There were no casualties.

Based upon a comparison between the effects of the 2009 SPT and those recorded in the trenches, the first event is likely to be associated with a tsunami sourced from the Tonga-Kermadec Trench region. The second event 2 is markedly larger than event 1 and there are several lines of evidence for a contemporaneous event in the South Pacific around 470BP.

Determining a source for this larger of the two events may be helped by numerical modelling of tsunami propagation and inundation We aim to use the Gerris program for the solution of the partial differential equations describing fluid flow (<http://gfs.sourceforge.net>) to model the generation, propagation and impact of tsunami generated by the 2009 PST and distant tsunami. The validation of the model will be provided by the survey of the 2009 PST and the paleotsunami study.

**WELL-LOG & WELL-CORE FRACTURE SYSTEMATICS APPLIED TO NUMERICAL
SIMULATION OF HEAT TRANSPORT SYSTEMATICS IN THE WAIKATO RIVER CENTRAL
TVZ DRAINAGE AREA**

Peter Leary, Peter Malin, Eylon Shalev & Stephen Onacha

Inst. Earth Science & Engineering, University of Auckland, Private Bag 92019,
Auckland
p.leary@auckland.ac.nz

The spatial correlation systematics of well-log and well-core fluctuations across the mm-to-km scale range provide a physical basis for numerically simulating fluid flow and heat transport within fractured/faulted crustal rock. At multi-km scales, the Waikato River course is spatially correlated with geothermal outcrops in the central TVZ where the Hauraki and TVZ fault trends intersect. Numerical simulation (using the SUTRA 3D Darcy flow/transport solver) of advective heat transport in intersecting fracture/fault crustal volumes indicates a substantial increase in percolation connectivity and heat transport for the intersection volume. Increased percolation connectivity and fluid flow at fault intersections correlates well with observed enhanced well production in geothermal field volumes where geophysical data indicate intersecting faults. The conceptual, field, and simulation evidence for increased percolation connectivity at fault intersections suggests that the Waikato River course and central TVZ geothermal outcrop siting are jointly influenced or controlled by faults at the Hauraki/TVZ rift intersection. These spatial correlations, if correctly interpreted, offer a basis for more quantitative understanding of the source and heat flow mechanics of TVZ and similar rift zone geothermal fields.

**MODELING BOREHOLE EVIDENCE FOR FRACTURE-BORNE ADVECTIVE HEAT FLOW
IN ORDINARY CRUST – SUTRA SIMULATION OF POROSITY-CORRELATED THERMAL
GRADIENT FLUCTUATIONS**

Peter Leary & Peter Malin

Inst. Earth Science & Engineering, University of Auckland, Private Bag 92019,
Auckland
p.leary@auckland.ac.nz

Wellbore data from a thermally equilibrated tight gas field reservoir show substantial spatial correlation between fluctuating well-log porosity ϕ and fluctuating well-log thermal gradient ∇T . The spatial correlation relation can be expressed analytically,

$$\delta \nabla T \approx P_e (T - T_0) / h \delta \phi, \quad (i)$$

in terms of advective heat transport by fluids percolating through fracture networks consistent with spatial correlation systematics of well-core and well-log data. The proportionality term in (i) comprises the Peclet ratio P_e of thermal advection to thermal conduction and the mean thermal gradient along the borehole data interval $h = 750\text{m}$. Relation (i) follows from two 'laws' expressing the role of grain-scale-fractures in creating multi-scale fracture-borne percolation pathways in crustal rock,

$$S(k) \sim 1/k, \quad (ii)$$

$$\delta \phi \sim \delta \log(\kappa), \quad (iii)$$

where $S(k)$ is the Fourier power-spectrum of well-log fluctuations at spatial frequencies k from 1cycle/cm to 1cycle/km, and $\delta \phi$ and $\delta \log(\kappa)$ are respectively the spatial fluctuations of the well-core porosity and the logarithm of well-core permeability. With (ii)-(iii) as physical basis for numerically simulating fluid-borne heat flow in crustal rock, the finite element Darcy flow/transport solver SUTRA in 2D reproduces (i) for parameters and boundary conditions appropriate to the tight gas reservoir. Simulation of (i) via (ii)-(iii) calibrates the use of physically realistic *in situ* poroperm complexity to better model fluid flow and heat transport in geothermal reservoir projects, and indicates that, at least in the presence of topography, advective heat flow can occur in ordinary crust where generally only heat conduction is considered.

**ZIRCON COLOUR REMOVAL ZONE AND U-PB AGES WITHIN THE SOUTHERN ALPS
AND IMPLICATIONS FOR SEDIMENT PROVENANCE**

S. Lee & P.J.J. Kamp

Dept. Earth and Ocean Sciences, University of Waikato, Private Bag 3105, Hamilton.
sp148@waikato.ac.nz

Geochronological analysis of zircon crystals is becoming an increasingly useful tool to establish the age, thermal history and provenance of rock successions. An obvious although poorly understood feature of zircons is their colour, which can vary from colourless to black. The Rakaia Subterranean greywacke and Alpine Schist rocks of the South Island present a continuous crustal section, which is ideal for studying the correlation between colour, geochemistry and U-Pb age of zircons. Colour proportions were analysed in 85 zircon separates from host rocks distributed across the Southern Alps, eight of which were subsequently U-Pb dated by LA-ICP-MS. The percentage of colourless zircon crystals increases with proximity to the Alpine Fault, demonstrating a removal of colour with increasing depth in the crustal section. Contouring the percentages identifies a 'colour removal zone', corresponding to the temperature range over which zircon colour is annealed, lying parallel to both the Alpine Fault and the metamorphic texture and facies zones, in accordance with the zircon and apatite fission track partial annealing zones. Samples containing 75% or more colourless zircons are located at the base of the garnet/oligoclase-amphibolite facies zone, corresponding to a crustal temperature of about 500°C. Samples containing less than 10% colourless crystals are located within the prehnite-pumpellyite zone. U-Pb ages of the eight analysed samples show a common Triassic age peak, demonstrating that the previously undated Alpine Schist rocks are indeed part of the same protolith as the greywacke part of the Rakaia Subterranean. The geochemistry of zircon colour generation still remains a mystery, as neither U-Pb age nor REE concentration show a discernible link to colour removal. Effective Uranium content showed a weak correlation with colour in some samples, with the concentration increasing in the yellow and amber zircons. Colour removal appears to be primarily driven by thermal conditions.

**VERTICAL SECTIONS REVEAL COMPOSITE, DYNAMIC VENTS OF A DIATREME, WEST
STANDING ROCKS, HOPI BUTTES VOLCANIC FIELD, ARIZONA, USA**

N.S. Lefebvre¹ & J.D.L. White¹

¹Dept. of Geology, University of Otago, PO Box 56, Dunedin.
lefna448@student.otago.ac.nz

Diatreme deposits present a partial record of pipe excavation and eruption processes, providing valuable information to better understand maar-diatreme eruptions. During eruption, the diatreme structure acts as a pathway for upward transportation of pyroclastic debris+fluid mixtures generated at explosion or fragmentation sites. Components of the pyroclastic debris indicate the location of the explosion site(s) and eruption style. The diatreme structure is also the depositional site for pyroclastic material falling back into or remaining within the vent during an individual eruption event, as well as for collapsed material from the maar collar or tephra rim.

Variable erosion across the early Pliocene Hopi Buttes Volcanic Field (HBVF) in northeastern Arizona has produced excellent 3D exposures of the harder subterranean volcanic features within the field. West Standing Rocks (WSR) is the exceptionally well-exposed remnant of a maar-diatreme volcano, situated in the central-southernmost part of the field, ~ 300 m below the pre-eruptive surface. WSR has been classified as a lower diatreme deposit based on its wide (8900 m²), kidney-shaped, ellipsoidal morphology; planar, subvertical external walls; and unbedded, homogenized nature of the pyroclastic infill. Internally WSR comprises multiple, narrow, generally massive, poorly sorted, well mixed tuff breccia domains with steep contacts. The domains are distinguished based on relative abundance of country rock xenoliths, juvenile clast types, and fragment size, as well as localized, subvertical clast alignment. These domains are interpreted as debris-filled vents preserved within the diatreme structure.

Based on the external diatreme shape and the presence of several cross-cutting vent-fills of varying compositions, multiple eruption bursts generated in different vertical and horizontal locations at various times can be inferred. Detailed volcanological mapping of the debris-filled vents reveals intricate relationships among intrusions, clastogenic coherent rock, pyroclastic rock and wall-rock debris; the WSR represents a composite and dynamic vent system.

**A NATIONAL TSUNAMI EVACUATION MAPPING FRAMEWORK: WARNING
PREPAREDNESS FOR COMMUNITIES INTEGRATING SOCIAL AND GEOSCIENCE BEST
PRACTICE**

G.S.Leonard¹, D.M.Johnston¹, W.Power¹, D.Coetzee², G.Downes¹, & B.Lukovic¹

¹GNS Science, PO Box 30368, Lower Hutt.

²Ministry of Civil Defence & Emergency Management, PO Box 5010, Wellington.
g.leonard@gns.cri.nz

The 2004 Indian Ocean tsunami stimulated great interest in the potential impact of tsunami on New Zealand. Reviews of tsunami risk and preparedness were completed in 2005, with recommendations to improve understanding of the risk and the effectiveness of tsunami warning arrangements. A national tsunami working group was convened to address these issues and their work included the development of a national signage standard and an evacuation mapping guideline.

The guideline draws upon (a) experience of emergency managers and communities internationally from social research over the past decade and (b) the latest tsunami source, propagation and inundation research. It sets out a framework presenting tsunami risk data in a simple format (zone maps) while still allowing adequate flexibility for evacuation (multiple zones). In future the lines on evacuation maps will likely move a little seaward as understanding of the hazard improves, but the terminology and zones remain the same, keeping the education and combined understanding consistent over time. The framework takes into account the differences amongst local, regional and distant-source tsunami and the varied natural, informal and official warning sources for each. It is calibrated to the content of Pacific Tsunami Warning Centre, GeoNet and National Warning System tsunami information. A focus on local community-derived map content aims to build community ownership and awareness, and make understanding and using the maps as simple as possible. Regular exercising of maps and plans is a core philosophy.

The guideline and signage standard were piloted in three Northland communities with community meetings, event briefings and surveys used to evaluate the framework and guide improvements. Use of maps and plans during the 2009 South Pacific and 2010 Chilean tsunami proved effective and mapping is currently underway or planned in communities in Northland, Bay of Plenty, Hawkes Bay, Horizons-Manawatu and Wellington Regions.

NGATAMARIKI GEOTHERMAL CHEMISTRY RIG (GCR) – FROM DESIGN TO COMMISSIONING

C.Lim

Mighty River Power Ltd, PO Box 245, Rotorua.
catherine.lim@mightyriver.co.nz

The silica dilemma has been plaguing our geothermal fields for many years. Acid dosing is widely known as the best method of silica control¹ to reduce scaling in pipeline and wells. To analyse the effects of pH modification on silica scaling a pilot plant was built to simulate actual plant operating conditions. This paper details the journey undertaken from conceptual design to commissioning of a pilot scale geothermal plant capable of simulating both flash and binary conditions.

The GCR design was based on previous rigs built in Rotokawa (binary) and Kawerau (flash). The key was to combine the two to provide flexibility in evaluating plant options. This also enabled the two plant processes to operate independently parallel. The design was reviewed internally and Dobbie engineering, who were hired to provide external consultation. Kevin Brown of Geokem was also regularly consulted as he has worked in many pilot scale rigs before. Modifications such as using electric actuators and controlling via DeltaV system were made to simplify operating the plant.

Constructing the pilot plant took approximately 4 months to complete before commissioning commenced mid-February 2010. Commissioning took 2-3 months as teething problems were resolved. In the flash plant, pH control was the main problem. For the binary rig, low pH cooling tower makeup water caused potential corrosion issues which were mitigated by adding corrosion inhibitors.

Based on commissioning results, operating procedures for both plants were adjusted accordingly to ensure optimum operation.

HOW VOLCANIC RISK METRICS CAN BE USED IN DECISION MAKING IN NEW ZEALAND

J. Lindsay¹, G. Jolly², L. Sandri³, W. Marzocchi³

¹School of Environment, The University of Auckland, Auckland

²GNS Science, Wairakei Research Centre, Taupo

³Istituto Nazionale di Geofisica e Vulcanologia, (INGV), Italy
j.lindsay@auckland.ac.nz

One of the main challenges of modern volcanology is to provide robust and useful information for decision-making around land-use planning and emergency management. We have been investigating the potential of two probabilistic codes that have been developed for quantitative short- and long-term eruption forecasting (Bayesian Event Tree for Eruption Forecasting, or BET_EF) and volcanic hazard assessment (BET_VH), to aid decision-making processes in future eruptions at two of New Zealand's volcanoes, The Auckland Volcanic Field (AVF) and Ruapehu.

In 2008 we set up BET_EF for the AVF by entering information on the past history of the AVF, as well as the monitoring signals "expected" in the event of an impending eruption. The code was tested during the 2008 nation-wide disaster exercise *Ruaumoko*, a simulated volcanic unrest in Auckland, where we tracked the probability of eruption, and forecast the most likely location of the initial phase of the simulated eruption. We then used the probabilities provided by the BET_VH code to carry out a cost benefit analysis (CBA) for evacuation in the event of base surge invasion.

Lahars have been generated as a result of several eruptions at Mt Ruapehu in the last 50 years, and some of these have reached the mountain's ski runs in a very short time frame (around 90 seconds from the beginning of the eruption). In our study we combine the probabilities of eruption-driven lahars, provided by BET_EF, with CBA to define the most rational mitigation actions that can be taken to reduce the risk to skiers, snowboarders and staff on the ski field.

Combining probabilistic hazard assessment with CBA provides a set of quantitative and transparent thresholds for decision making that can be established *before* a crisis, and shows great potential for optimizing and clarifying decision-making procedures at New Zealand volcanoes.

GEOPHYSICAL CHARACTERISTICS OF EPITHERMAL DEPOSITS IN THE SOUTHERN HAURAKI GOLDFIELD, NEW ZEALAND

C.A. Locke¹, J. Cassidy¹, M.C. Harris², A.L. Kirkby³, J.L. Mauk¹ and A.E. Morrell⁴

¹School of Environment, The University of Auckland, PB 92019, Auckland 1142

²Golder Associates Ltd, PO Box 33-849, Takapuna, Auckland 0622

³Geoscience Australia, GPO Box 378, Canberra, ACT 2601, Australia

⁴Southern Geoscience Consultants, 8 Kearns Cres, Ardross, WA 6153, Australia
c.locke@auckland.ac.nz

The southern province of the Hauraki Goldfield in the Coromandel Volcanic Zone (CVZ) contains approximately 15 epithermal deposits that are hosted by Late Miocene-Pliocene andesite flows. Regional gravity data from the southern CVZ are dominated by steep linear gravity gradients that delineate the major fault that bounds the Hauraki Graben to the west, and other large faults associated with the Waihi trapdoor caldera in the east. Regional magnetic data are dominated by a large bi-polar anomaly, coincident with the Waihi Caldera, which may result from a sub-caldera intrusion; otherwise, high-amplitude shorter wavelength magnetic anomalies are characteristically associated with the volcanic rocks. High-resolution magnetic and radiometric data reveal distinctive signatures associated with epithermal deposits. Extensive magnetically quiet areas delineate the location and extent of destruction of magnetite in the host volcanic rocks, which effectively maps the hydrothermal alteration zones that surround these deposits. The analytic signal is particularly effective in locating these zones, including some in areas of thin post-mineral cover. Broad-scale high K/Th anomalies are associated with pervasive low-rank alteration whereas localised zones of high potassium count within magnetically quiet areas delineate potassium enrichment, which reflects significant potassic alteration. The epithermal deposits exhibit two contrasting types of gravity signatures: 1. small negative anomalies (for example, ≤ 30 g.u. at Golden Cross and Scotia) and 2. small positive anomalies (for example, 30-50 g.u. at Karangahake and Waihi-Favona). Near-surface, low density clay-altered andesites can account for the observed small negative gravity anomalies. However, given the ubiquitous occurrence of such altered andesites, the positive gravity signatures indicate that significant mass anomalies must occur at greater depths; these may be either dense intrusions and/or zones of relatively enriched sulphide mineralisation.

A NEW METHOD OF OBTAINING HIGH-RESOLUTION PALEOCLIMATE RECORDS FROM SPELEOTHEM FLUID INCLUSIONS

A.J. Logan¹ & T.W. Horton¹

¹Dept. of Geological Sciences, University of Canterbury, PB 4800, Christchurch 8140
andrea.logan@pg.canterbury.ac.nz

We present a new continuous-flow method for stable hydrogen and oxygen isotope analysis of ancient drip water trapped within cave speleothems. Published thermal extraction and crushing methods require large samples in excess of c. 150 mg of calcite. Our method improves on existing fluid inclusion isotopic analytical techniques in that it decreases the sample size by a factor of ten or more, dramatically improving the spatial and temporal precision of fluid inclusion-based paleoclimatology.

Our method combines relatively low-temperature ($\sim 300^\circ\text{C}$) thermal decrepitation with cryogenic trapping across a switching valve sample loop. In brief, ~ 20 mg carbonate samples are dried (75°C for >1 hour) and heated (300°C for >1 hour) in a quartz sample chamber under a continuously flowing stream of ultra-high purity helium. Fluids released during the heating step are trapped in a coiled stainless steel cold trap ($\sim -98^\circ\text{C}$) serving as the sample loop in a 6-way switching valve. Trapped fluids are subsequently injected into a high-temperature conversion elemental analyzer by switching the valve and rapidly thawing the trap. This approach yields accurate and precise measurements of injected liquid water IAEA reference materials (GISP; SMOW2; SLAP2) for both hydrogen and oxygen isotopic compositions. Blanking tests performed on the extraction line demonstrate extremely low line-blank peak heights ($<50\text{mv}$). Our tests also demonstrate that complete recovery of liquid water is possible and that a minimum quantity of $\sim 100\text{nL}$ water was required. In contrast to liquid water analyses, carbonate inclusion waters gave highly variable results. As plenty of signal was produced from relatively small sample sizes (~ 20 mg), the observed isotopic variation most likely reflects fractionation during fluid extraction, or natural isotopic variability.

Additional tests and modifications to the extraction procedure are in progress, using a recently collected New Zealand stalagmite from a West Coast cave (DOC collection permit WC-27462-GEO).

SEPARATOR PERFORMANCE AND STEAM PURITY TESTING USING CHEMICAL TRACING TECHNIQUES

B. Lovelock

Sinclair Knight Merz, Level 2 Carlaw Park, 12-16 Nichols Lane, Parnell, New Zealand
blovelock@skm.co.nz

Ensuring high steam purity at the turbine relies upon good separator performance and efficient steam line scrubbing of brine carryover. Quantifying separator and scrubbing performance are often a requirement of power station performance testing and several chemical tracing techniques have been developed to do this. The procedures are based upon the measurement of total chloride flux through the steam line system or by injection and recovery of chemical tracers. Examples of such testing are presented and the benefits explained. Conducting this testing relies upon suitable sampling points being in place and these should be included in the original engineering design. These requirements are explained.

USING TEPHROCHRONOLOGY TO DEFINE AND DATE THE BASE OF THE HOLOCENE FOR AUSTRALASIA AT LAKE MARATOTO, NEW ZEALAND: AN AUXILIARY STRATOTYPE

David J. Lowe¹ & Rewi M. Newnham²

¹Dept Earth & Ocean Sciences, University of Waikato, Private Bag 3105, Hamilton

²School Geog., Environ. & Earth Sci., Victoria Univ. of Wellington, Box 600, Wellington

d.lowe@waikato.ac.nz

Although the Holocene was recognised as a stratigraphic unit of series status in 1885, a proposal defining its base (Pleistocene-Holocene boundary, PHB) was not ratified by IUGS until 2008. The Holocene Global Stratotype Section and Point (GSSP) is at 1492.45 m depth in NorthGRIP ice-core and marks initial warming after the YD/Greenland Stadial-1 cold phase at $11,700 \pm 99$ cal. yr b2k. Five global auxiliary stratotypes are recognized, the PHB being defined using tephra layers in lake sediments in three regions including Australasia where the auxiliary GSSP is at Lake Maratoto (LM). LM near Hamilton is one of >30 small lakes in the Waikato lowlands formed ~20 cal. ka. It preserves a continuous sedimentary sequence since the LGM from which detailed tephrostratigraphic, pollen, and other palaeoenvironmental records have been obtained. Extensive stratigraphic surveys (33 lake cores, GPR, 34 ¹⁴C dates) enabled reconstruction of the LM's development. The PHB was pinpointed using tephrostratigraphy and palynostratigraphy: full Holocene warmth occurs near the time of deposition of Egmont-derived Konini Tephra (KT) at $11,720 \pm 220$ cal. yr BP (2σ). KT was correlated via its hornblende-clinopyroxene mineralogical assemblage and by glass-shard EPMA. In a 3-m long core (X79/1), KT is a pale grey fine-ash layer 2-3 mm thick ~1.50 m below Taupo tephra and lies between two distinctive markers: a greyish-black andesitic ash (Mangamate) lies above it (1.40–1.45 m), and a white and cream, fine and medium-bedded rhyolitic ash (Waiohau) lies below it (1.67–1.70 m). Attainment of full climatic warmth associated with the onset of the Holocene at around the time of deposition of KT has been reported from other North Island pollen sites. LM, 1.5 km west of SH 3, is easily accessed by farm road and, although on private land, is protected from any development by a QE II covenant.

USING TEPHROCHRONOLOGY TO UNRAVEL UPBUILDING PEDOGENESIS IN TEPHRA AND LOESS SEQUENCES IN NEW ZEALAND

David J. Lowe¹ & Philip J. Tonkin²

¹Dept Earth & Ocean Sciences, University of Waikato, Private Bag 3105, Hamilton 3240

²Dept Soil & Physical Sciences, PO Box 84 Lincoln University, Lincoln 7647, Canterbury
d.lowe@waikato.ac.nz

Tephrochronology is a stratigraphic method for linking, dating, and synchronizing geological, palaeoenvironmental, or archaeological sequences or events. We use it as a chronostratigraphic tool to examine rates and processes involved in the evolution of late Quaternary soils in New Zealand via upbuilding pedogenesis on tephras (typically forming Andisols) and loess (typically forming Alfisols). In such landscapes, soil evolution is complex because the impact from topdown pedogenic processes is modified by the rates at which new materials are added to the land-surface via geological processes. Many Andisol profiles form by upbuilding pedogenesis as younger tephras are deposited on top of older ones. The frequency and thickness of tephra accumulation determine how much impact the topdown processes have on the ensuing profile character, and if 'developmental' and/or 'retardant' upbuilding will occur. Two scenarios are considered. (1) Successive thin tephra deposits (millimetres-to-centimetres in thickness) accumulate incrementally and relatively infrequently so that developmental upbuilding ensues, as occurs at distal sites. (2) Tephra accumulation is rapid, as occurs close to volcanoes, or when a relatively thick layer (>several tens-of-centimetres in thickness) is deposited from a powerful eruption. The antecedent soil is suddenly buried and isolated beyond the range of most soil-forming processes. A new soil will thus begin forming at the land-surface in the freshly-deposited material. This scenario typifies retardant upbuilding, which means that the development of the now-buried soil has been retarded/stopped. In loess terrains, upbuilding pedogenesis since ~25 ka is associated with maximum rates of loess accumulation ~3-10 mm per century during glacials/stadials, sufficiently slow for soil-forming processes to continue to operate as the land-surface gradually rises. Thus, Alfisol subsoil features are only weakly developed. In contrast, topdown pedogenesis is associated with minimal or zero loess accumulation during interglacials/interstadials, the land surface elevation remains essentially constant, and subsoil features become more strongly developed.

USING EARTHQUAKE CLUSTERS TO IDENTIFY FRACTURE ZONES AT PUNA GEOTHERMAL FIELD, HAWAII

A. Lucas, E. Shalev, P. Malin & C. Kenedi

Institute of Earth Science and Engineering, University of Auckland, Auckland.
a.lucas@auckland.ac.nz

The actively producing Puna geothermal system (PGS) is located on the Kilauea East Rift Zone (ERZ), Hawaii. In the Puna area the rift trend is identified as NE-SW from surface expressions of normal faulting, at PGS the rift offsets in a left step. The spread of earthquake locations follows the rift trend. Double difference (DD) relocation of all earthquakes identified one large cluster but could not conclusively identify trends within the cluster. For five stations out of the six where shear wave splitting was observed, the dominant polarization direction was rift parallel. Two of the five stations also showed a smaller rift perpendicular signal. The shear wave splitting time delays indicate that fracture density is higher at the PGS compared to the surrounding ERZ. Correlation co-efficient clustering was used to identify clusters based on similar earthquake waveforms. In total, 40 localized clusters containing ten or more events were identified. Most of the clusters had linear features when their locations were plotted and were further enhanced by DD relocation. The concentration of individual linear features was higher in the PGS than the surrounding ERZ. Mapping of the linear features showed that a number of the larger features ran rift parallel. However a large number of rift perpendicular features were also identified. We assume that events occurring on the same fracture zone have similar source mechanisms and thus similar waveforms. It is concluded that the linear features identified by earthquake clustering are fracture zones. The orientation and concentration of the fracture zones is consistent with that of the shear wave splitting polarizations.

A SEAMLESS 1:250 000 GEOLOGICAL MAP DATASET

Biljana Lukovic¹, Dave Heron¹ and Richard Jongens²

1 GNS Science, P.O. Box 30-368, Lower Hutt

2 GNS Science, Private Bag 1930, Dunedin

b.lukovic@gns.cri.nz

The QMAP 1:250 000 Geological Map of New Zealand programme is almost complete with just one map still to be published. One of the last tasks has been to create a seamless GIS dataset. Data for all but the last few completed maps have been merged into a single dataset and that has been done across multiple data layers - principally geological units, horizons, faults, folds, landslides, dikes, linears, textural zones, and metamorphic zones. This process involved adjusting mismatching lines and polygons across sheet boundaries. The mismatches have resulted from small differences in data capture accuracy and new geological interpretation on adjacent map sheets.

The project is also increasing the richness of the geological GIS data. Stratigraphic detail has been added to geological unit, horizon and dike layers. Simplified rock descriptions (e.g. Torlesse sandstone), stratigraphic ages (e.g. Triassic-Jurassic) and gross groupings (e.g. of basement rocks) have been added to make map creation using a GIS simpler and also allowing more ways of viewing the same data.

The Seamless QMAP GIS will become the most current version of the QMAP dataset and will be updated periodically. Attribution (e.g. age, isograds) associated with widely occurring units (e.g. Torlesse) and textural-metamorphic zones will be reviewed to achieve consistency across QMAP sheet boundaries.

The data will be made available on CD, through a web map application, and through a web feature service that enables access of the seamless vector data via the internet.

MAPPING THE SPATIAL EXTENT OF BURIED HOT SPRING DEPOSITS IN NEW ZEALAND AND THE USA USING GROUND PENETRATING RADAR

B.Y. Lynne¹ & A.J. Dougherty¹

¹Institute of Earth Science and Engineering, University of Auckland, Private Bag 92019, Auckland.

b.lynne@auckland.ac.nz

Discharging hot springs are surface expressions of a deeper geothermal reservoir. As the discharging hot spring fluid cools, silica carried in solution precipitates and entombs all components, such as microbes within the discharge channel. This silica accumulates to form rocks referred to as sinters. Geothermal reservoirs and sinter deposits remain long after hot spring discharge ceases. Therefore ancient sinters provide a direct link with a deeper potentially exploitable geothermal resource in areas where there are no present-day discharging hot springs.

High, mid and low-temperature microbes create distinctive environmentally-significant textures that are preserved with time and throughout diagenesis (opal-A to quartz). Diagenesis is accompanied by a density increase and porosity decrease. The variety of sinter textures, density and porosity values and the low conductive/high resistive siliceous rocks make GPR a suitable tool for imaging sinters.

Previously, geologists have been constrained to examining sinters in locations where they are exposed. Our results from both New Zealand and the United States show Ground Penetrating Radar (GPR) was successful in geothermal environments by: (1) imaging through opal-A to quartzose sinters allowing the sinter thickness to be mapped giving a better indication of the amount of fluid flow to the surface; (2) mapping hot spring environments such as high temperature vents and low-temperature distal-apron terraces; (3) locating the true spatial extent of partially buried sinters; (4) imaging completely buried sinters.

The combination of sinter mapping using outcrop and GPR complements standard techniques used in assessing a geothermal resource. This new methodology provides a non-invasive, cost-effective technique for assisting in geothermal exploration and in identifying hidden geothermal reservoirs.

**MULTI-PROXY RECORD OF LATE HOLOCENE ENVIRONMENTAL CHANGE
FROM LAKE COLENZO, NORTHERN RUAHINE RANGE.**

A. M. MacDonald-Creevey¹, V. E. Neall¹, K. A. Holt² & M. J. Vandergoes³

¹Soil and Earth Sciences, Massey University, Palmerston North.

²School of People, Environment and Planning, Massey University, Palmerston North.

³GNS Science, 1 Fairway Drive, Avalon, Lower Hutt.

A.MacDonald-Creevey@massey.ac.nz

Lake Colenso is a small, isolated lake located in the northern Ruahine Range, at an altitude of 720 m. Field mapping and aerial photography indicate the lake was formed by a landslide damming event, potentially triggered by a major earthquake on a nearby fault. Sediment cores extracted from the lake have been analyzed in a two-fold approach: to investigate the timing of lake formation with respect to palaeoseismic records of the nearby Wellington and Ruahine faults; and to develop a high-resolution, multi-proxy record of late Holocene environmental change from the central North Island. Radiocarbon dating of basal sediments returned an age of 1799 ± 73.5 cal yr BP, taken as the age of the landslide upon which the lake is situated. Subsequent soil formation dominates the core until a succeeding landslide blocked the drainage and initiated formation of the lake. Cores have been processed for pollen, ostracods, tephra, C, N, and grain size to provide a detailed record of climate variability over the late Holocene. Tephra horizons combined with radiocarbon ages provide a chronology for the record. Preliminary pollen analyses indicate minimal human influence in the lake catchment; thus the site offers a rare opportunity to investigate natural environmental change during a period in which anthropogenic impacts have tended to obscure natural variability in many records from elsewhere in New Zealand. Grain size analysis and C and N values have been used to develop a record of storm frequency in the lake catchment; storm events are preserved at a centennial time-scale with an average of 1 event every 150 years. Oxygen isotope analysis of freshwater ostracods will be used in an attempt to develop a palaeohydrological record of the lake, the first such record produced from New Zealand.

**KARANGA WHENUA ATU, KA RONGO, KA MAU, KA MARAMA TANGATA MAI
(WHEN THE LAND CALLS, THE PEOPLE WILL HEAR, LISTEN AND UNDERSTAND)**

M. Marra¹, D. Hikuroa² and C. Frericks³

¹WPC, University of Waikato, Private Bag 3105, Hamilton

²Institute of Earth Science & Engineering, University of Auckland

³School of Environment, University of Auckland

mmarra@waikato.ac.nz

Throughout time people have created stories to explain the world they live in and these are passed through generations via myth, symbols, oral tradition (stories that extend further than one generation) and art. Mythology and oral tradition are rich in their descriptions of natural events, but very few have been related to actual events. Many communities have their own calendars, usually related to extraordinary events, but in the majority of cases, the calendars are either difficult to interpret or do not reach further into the past than one or two generations. One exception is Hawaiian oral tradition, where the record of volcanic events reaches back more than 1,000 years. Hawaiian oral tradition has survived intact because stories are embedded in their genealogy and are recited at important events. These stories match perfectly with the chronometrically dated natural events.

Maori also have a strong oral tradition relating to physical events. Like the Hawaiian example, Maori oral tradition is similar in that the reciting of genealogies is well developed and its function is in the recounting of history and tradition. As an example, Tuhoe, have an oral tradition that reaches back beyond 1,000 years and includes reference to geologic events. For example the korero describes that the Waimana River flowed into the Ohiwa Harbour. This is different from the modern day course of the Waimana in that it departs from its north/south course to flow westward into the Whakatane River. Geomorphically it appears to have been captured by the Whakatane, and our data show sedimentation rate at the coast decreased since the Taupo eruption (232 +/- 15 AD), which may relate to the loss of the Waimana from the system. This particular korero illustrates that oral tradition has considerable potential to provide key observational details about significant natural events.

ARE THE OROCLINES OF THE IBERIAN MASSIF RELATED TO LATE VARISCAN STRIKE-SLIP TECTONICS?

J.R. Martínez Catalán

Depto. Geología, Universidad de Salamanca, 37008 Salamanca, Spain.
jrmc@usal.es

The Central Iberian arc (Martínez Catalán, J.R. 2010. Geological Society of America, Abstracts with Programs, Vol. 42, No. 5, p. 34) is a recently described orocline whose core is occupied by several allochthonous terranes, including ophiolites marking the suture of the Rheic Ocean. The arc is delineated by the trend of the Variscan folds and by magnetic anomalies. It shares its northern flank with the Ibero-Armorican arc, both being similar in size but of opposite curvature. The relationship between the Central Iberian arc and the dextral Porto-Tomar shear zone reminds that of the dextral Alpine fault with the orocline affecting the Otago schists, the Permian Dun Mountain ophiolite belt, and the Junction magnetic anomaly in the South Island of New Zealand. The Central Iberian arc, however, nearly doubles in size its younger counterpart.

The Porto-Tomar shear zone is folded by the Ibero-Armorican arc, indicating a later development of this arc in relation to the Central Iberian arc. A transcurrent model is presented to explain the genesis and evolution of the two oroclines identified in the Iberian Massif. Moreover, a simple plate tectonics scenario is proposed that links late Variscan dextral strike-slip movements in the Variscides to a broad intracontinental shear zone, kinematically equivalent to a transform fault, and which accounts for orocline development.

LANDSLIDE MONITORING AND ITS APPLICATION TO RISK MANAGEMENT, WITH REFERENCE TO THE UTIKU AND TAIHAPE LANDSLIDES, NEW ZEALAND

C. Massey¹, M. McSaveney¹, D. Petley²

¹GNS Science, Lower Hutt

²Department of Geography, Durham University, UK
c.massey@gns.cri.nz

The Taihape and Utiku landslides are two of over 7,000 mapped large landslides in the Tertiary-age sedimentary rocks that cover about 17% of New Zealand. The majority of these landslides are inferred to be slow-moving, relatively deep-seated, translational rock slides.

Surface movement of the Taihape landslide is monitored using 35 prisms surveyed by a permanent robotic total station. Surface movement of the Utiku landslide is monitored with 4 continuous GPS stations. Rainfall, pore pressures, earthquake ground accelerations and subsurface displacements are also monitored at each landslide. The precision and temporal resolution of the landslide monitoring data clearly resolves the triggers for the movement as well as the resulting complex movement patterns, including seasonal movement unrelated to landslide motion. The movement patterns of the Utiku and Taihape slides are best described as post – failure episodic creep, comprising steady slow creep at rates < 10 mm/year sustained over months and years, punctuated by periods of rest and accelerated creep at rates of 1 - 3 mm/day sustained over weeks. Near real-time monitoring of these two particular landslides, at high temporal and spatial resolutions has provided a much better understanding of how rainfall links to landslide movement via groundwater levels. These are compared with the longer historical and geomorphological record and allow quantification of the location, probability and magnitude of expected movements.

The hazards posed by these landslides have been quantified, and strategies have been implemented to manage the risks that they pose. At Taihape, it is the risk to the local community living on the landslide, while at Utiku, it is the risk to the North Island Main Trunk railway line and State Highway 1. The risk management strategies adopted for the two landslides are based on trigger levels linked to pore pressure conditions and to rates and magnitudes of surface displacement. These levels are used to trigger particular actions, as set out in the emergency management plan for each landslide. These plans are unique to each landslide and reflect the particular vulnerabilities of the facilities at risk.

BOREHOLE ACOUSTIC IMAGING IN HIGH TEMPERATURE GEOTHERMAL NEW ZEALAND SYSTEMS

C. Massiot¹, D. McNamara¹, M. Lawrence² & G. Bignall¹

¹ Wairakei Research Centre, GNS Science, PB 2000, Taupo 3352

² Avalon Research Centre, GNS Science, PO Box 30-368, Lower Hutt 5040
c.massiot@gns.cri.nz

Since July 2009, a borehole acoustic televiewer (BHTV) with high temperature capability has been run in ten wells in four New Zealand geothermal fields (Ngatamariki, Rotokawa, Kawerau, and Wairakei). This wireline logging technique uses travel time and amplitude of acoustic waves to generate an image of the borehole wall. Interpreted images provide information on borehole shape, host rock fabric and fractures (i.e. filled and open, natural and drilling induced fractures, based on contrasting acoustic wave attenuation), orientation of in-situ stress in the reservoir, and information that can refine the depth of lithological contacts inferred from drill cuttings.

Interpretation of fracture distribution, orientation and aperture provide insights on structural controls on permeability within the reservoir, including the extent and displacement of fault zones, and fault plane orientations. In-situ stress orientation is determined from interpretation of borehole tensile fractures and breakouts observed on the acoustic image. The interpreted data provides insight on which fracture orientations are likely open to fluid flow (i.e. potential well feed zones), and can be combined with stress magnitudes to quantify critical stress-related permeability and borehole stability. Fracturing and in-situ stress data from feed zones, together with other physical well measurements (e.g. temperature, spinner), allows the contribution of fracturing to permeability and direction of fluid flow to be assessed.

Multi-well borehole acoustic image correlation, combined with well data, provides an insight on field compartmentalisation, barriers and pathways for fluid flow. Combined with 3D-modelling, acoustic image data can be used to visualise reservoir structures and the effect of fracture and fault-systems on continuity of permeable strata. In this paper we highlight the value of BHTV as a complementary tool for well targeting and field management, and potential application for assessing the nature of fluid flow, and consequently resource potential, of "hotter and deeper" geothermal resources in the Taupo Volcanic Zone.

**SOUTH POLAR FLORA AND ENVIRONMENTS:
MID-CRETACEOUS BIOSTRATIGRAPHY OF THE CHATHAM ISLANDS, NEW ZEALAND**

C. Mays, J.D. Stilwell & M. Hall

Monash University, School of Geosciences, Clayton 3800, Victoria, Australia
chris.mays@monash.edu

The Chatham Islands are home to arguably the highest palaeolatitude mid-Cretaceous fossil plant locality of the Southern Hemisphere. As such, the palaeoenvironment may represent the most extreme climatic conditions of the mid-Cretaceous; the floral ecology should reflect this. This study stratigraphically logged two sedimentary sequences of the mid-Cretaceous Tupuangi Formation, Chatham Islands, and 41 palynomorph samples were retrieved and processed for biostratigraphic analysis. An age of Cenomanian to lower Turonian was derived, which supports the notion of a failed-rift basin in eastern Zealandia prior to sea-floor spreading between Zealandia and Antarctica in the Late Cretaceous. Relative abundances of pollen and spores indicate a floral ecology dominated by conifers (primarily Cupressaceae, Podcarpaceae & Araucariaceae), with minor seed-ferns, ferns, ginkgos, lycophytes, bryophytes and angiosperms. There is a rise in microplankton and angiosperm microfossil abundance and diversity, suggesting increasing marine influence and basinal subsidence, as well as the initial stages of angiosperm dominance at southern polar latitudes.

MAGMA PLUMBING SYSTEMS IN THE AUCKLAND VOLCANIC FIELD: A URANIUM SERIES PERSPECTIVE

Lucy McGee¹, Christoph Beier^{2,3}, Ian Smith¹ & Simon Turner²

¹School of Environment, University of Auckland

²GEMOC, Macquarie University, Sydney, Australia

³Now at GeoZentrum Nordbayern, Universität Erlangen-Nürnberg, Germany
l.mcgee@auckland.ac.nz

Rangitoto volcano is the most recent eruption in the Auckland volcanic Field at ~500yr BP is unusual in that it erupted magmas of alkalic then subalkalic basaltic composition in discrete events separated by ≤ 50 years. Major and trace element geochemistry together with Sr-Nd and U-Th-Ra isotopes provides the basis for modelling the melting conditions that brought about the eruption of two chemically different lavas with very little spatial or temporal change. The basalts show high ²³⁰Th-excess compared to comparable continental volcanic fields. We model that the chemical differences between the two suites are due to variable amounts of garnet in the source, and very small degrees of melting, a longer melt column and lower upwelling and melting rates for the initial alkalic eruption compared with the second, more voluminous subalkalic eruption. The low upwelling rates (0.3-1.3cm/yr) modelled for both magmas do not suggest a plume or major upwelling in the mantle region beneath Auckland. A higher porosity for the initial alkalic basalt is based on ²²⁶Ra-excesses, suggesting movement of melt by two different porosities: the initial melt travelling in fast high porosity channels from greater depths preserving a high ²³⁰Th-excess, and the subsequent subalkalic magma travelling from a shallower depth through lower porosity diffuse channels and preserving a high ²²⁶Ra-excess; this creates a negative array in (²²⁶Ra/²³⁰Th) vs. (²³⁰Th/²³⁸U) space previously only seen in Mid Ocean Ridge Basalt data. This mechanism suggests the Auckland Volcanic Field may operate by the presence of discrete melt batches which are able to move at different depths and speeds giving the field its erratic spatial and temporal pattern of eruptions, a type of behaviour that may have implications for the evolution of other continental volcanic fields worldwide.

MATHEMATICAL MODELLING OF AEROSOL TRANSPORT: EFFECT OF DISPERSION COEFFICIENTS ON PREDICTED GROUND DEPOSITS

R. McKibbin

Centre for Mathematics in Industry, Massey University, PB 102-904 NSMC, Auckland
R.McKibbin@massey.ac.nz

Solid and liquid particles (aerosols) ejected into the atmosphere by volcanic or hydrothermal eruptions, dust and sand swept up by storms, particles from industrial emissions and droplets from crop-spraying, are subsequently dispersed by atmospheric wind currents. The particles fall under gravity while being advected by the mean wind and dispersed by turbulence. In general, particle sizes are not uniform; they may also change during flight, by particle coalescence and/or fragmentation, by adsorption, or by fluid evaporation or condensation. The wind (speed, direction and dominant turbulence length scales) may also change with elevation (and with time). Some particles may be trapped on crop or forest foliage as they near the ground.

Here, the focus is instead on the rôle of the dispersion coefficients in the solutions of the governing equations. A cohort of uniformly-sized particles is released from an elevated point into a uniform wind; they eventually fall to the ground with no change in size or settling speed. The vertical, transverse and longitudinal dispersion coefficients are then each assumed to be separately zero, and the effects on the calculated ground deposits are compared and discussed. It is shown that neglect of vertical dispersion produces profiles that lack the characteristic long downwind tail of observed deposits (from volcanic ashfall, for example). Neglect of transverse dispersion produces narrow deposits; however, the solution may be useful for line source releases. Without longitudinal dispersion included, the particle motion is not physically realistic, even though the predicted deposit distribution coincidentally has features that are similar to that predicted when all dispersion coefficients are non-zero.

Releases of cohorts of variously-sized particles at different elevations, such as from a volcanic eruption, are also modelled. The consequent ashfall distribution on the ground is computed under the above assumptions, and the results are discussed.

SOLVING SILICA SCALE WITH *AB INITIO* CALCULATIONS: HIGH HOPES AND HURDLES

G.J. McIntosh & P.J. Swedlund

Dept. of Chemistry, University of Auckland, Private Bag 92019, Auckland, New Zealand
p.swedlund@auckland.ac.nz

Energy extraction from geothermal fluids can produce solutions that are supersaturated in silicic acid (H_4SiO_4). Despite volumes of research silica scale remains a challenging constraint to enthalpy extraction because H_4SiO_4 polymerization proceeds via a multitude of reactions and there are many variables in fluid composition and conditions. The large number of processes and variables means that computational methods have great potential to provide insights into managing silica polymerization. *Ab initio* methods are based on the first principles of quantum mechanics which means that they can elucidate chemical systems that are not adequately described by existing thermodynamic and kinetic models. In the last decade there has been a dramatic increase in the ability of *ab initio* methods to provide highly accurate descriptions of the chemistry of complex systems that are either in the gas phase or in crystalline solids. Applying these methods to solution systems remains a challenge because solvation involves a very large number of low energy interactions. This paper discusses applying *ab initio* methods to silica polymerization and uses our recent study of the properties of H_4SiO_4 and D_4SiO_4 solutions to illustrate some of the opportunities and obstacles.

THE TASMAN GLACIER AS A CLIMATE INDICATOR: A MODELING APPROACH

K. McKinnon¹, A. Mackintosh¹ & B. Anderson¹

¹Antarctic Research Center, Victoria University, PO Box 600, Wellington, New Zealand.

karen.mckinon@vuw.ac.nz

Mountain valley glaciers can provide valuable information about the climate of the past and present because they are sensitive to temperature and precipitation and are relatively simple physical systems. Furthermore, the global glacial moraine record demonstrates substantial spatial coherence, implying that the record left in mountain glacier moraines reflects large-scale climate rather than local effects. We examine the relationship between climate and glacial extent through the employment of a coupled flowline-energy balance model, focusing on the Tasman Glacier in New Zealand. The sensitivity of the glacier to changes in mean temperature, annual precipitation, orbital parameters, strength of the seasonal cycle in temperature, bed geometry and lapse rate is explored. Modelled glacial extent as a function of these climatic variables is compared to present day extent for model validation. Subsequently, the model is used to determine an envelope of climatic conditions that lead to the Last Glacial Maximum glacial extent, offering climatic constraints from the well-constrained glacial record.

REFINEMENT OF FEED ZONE INTERPRETATION FROM COMPLETION TESTING USING AFIT

K. McLean¹ & D. McNamara²

¹Contact Energy, Wairakei Power Station, Private Bag 2001, Taupo, NZ.

²GNS Science, Wairakei Research Centre, Private Bag 2000, Taupo, NZ.

katie.mclean@contactenergy.co.nz

Permeable feed zones in geothermal wells are currently defined using completion test data such as well temperature, pressure and fluid velocity profiles. While the completion test gives some indication of the depth and relative strength of the feed zones it does not give any information on the nature of the permeability in those zones, be it intrinsic or secondary. Permeable zones targeted for reinjection and production in the Wairakei Geothermal Field lie within the variable lithologies of the Waiora, Waikora and Tahorakuri formations, where fracturing is thought to contribute to permeability. By characterising information such as fracture orientation, density and width, as well as determining the orientation of the horizontal stress field it is possible to determine the fracture component of the well permeability. This has implications both for well targeting and reservoir modelling.

The recent use of high temperature acoustic formation imaging technology (AFIT) can provide the necessary fracture and stress data to assess the contribution of fractures to feed zone permeability. As part of an ongoing AFIT program at Wairakei, data has been collected from the open hole of three wells prior to running the liner, WK404 and WK407 in the South Karapiti reinjection area and WK317 in the Otupu reinjection area.

The location of feed zones in these three wells has been interpreted from the completion test data and then refined using AFIT data to provide more accurate locations and information on the nature of permeability. Fracture density, width and orientation were correlated with responses in the completion test data. Only fractures with optimal orientation within the local stress field are considered as potentially open to fluid flow. While the correlation between feed zones from the completion test and fracture density is poor, very good correlation is observed with the location of individual wide-aperture fractures.

CORRELATION OF STRUCTURALLY CONTROLLED PERMEABILITY BETWEEN GEOTHERMAL WELLS USING AFIT

D. McNamara¹, K. McLean²

¹GNS Science, Wairakei Research Centre, Private Bag 2000, Taupo, NZ

¹Contact Energy, Wairakei Power Station, Private Bag 2001, Taupo, NZ

Deep permeable zones, targeted for reinjection and production in the Wairakei Geothermal Field, commonly lie within competent Tahorakuri Formation rocks, where faulting and fracturing is thought to dominate permeability. Therefore it is essential to understand the characteristics of these structures (orientation, density, aperture and orientation to the local stress field) in order to assess their contribution to permeability in well feed zones and the interconnectivity of structurally controlled fluid flow between wells.

The recent use of high temperature acoustic formation imaging technology (AFIT) can provide the necessary fracture and stress data to assess fracture permeability in a well or reservoir. This data has been acquired from two vertical wells drilled from the same pad in the South Karapiti reinjection area of the Wairakei Geothermal Field (WK404, WK407).

Prior to drilling well WK407, AFIT data collected in well WK404 was used to assess whether feed zones of that well were controlled by fracturing. The aim was to target permeable fracture zones in well WK407 as predicted by extrapolation of structural trends observed in well WK404. Subsequent to drilling well WK407, correlation of AFIT data from both wells was carried out investigate whether the well targeting aim was achieved. Using completion test data to define feed zone depths in both wells, structural data for each zone is assessed and compared to correlate and link structurally controlled fluid flow pathways between these two wells.

This study, if extrapolated field wide, demonstrates the capability acoustic borehole imaging has for higher precision well targeting and geothermal field management.

RECORDED STRONG GROUND MOTIONS AND ENGINEERING DESIGN LEVELS IN THE DARFIELD EARTHQUAKE

G.H. McVerry¹

¹GNS Science, PO Box 30368, Lower Hutt.
g.mcverry@gns.cri.nz

An extensive set of strong ground-motion records allows assessment of the effects of the Darfield Earthquake in terms of their causative motions, and comparisons of the motions with current New Zealand design levels.

Near-source motions reached between 2500- and 5000-year values at Greendale, and about 1000- to 2500-year levels at Hororata, compared to the 500-year design-level used for normal-importance structures. Peak horizontal ground accelerations (phgas) exceeded 0.5g at Greendale and Darfield. Vertical accelerations were over 1g at Greendale and 0.7g on four other records. Peak ground velocities reached 1.5m/s at Greendale, and over 0.5m/s at three other sites. For some records, polarisation directions changed during the motions, consistent with rupture-directivity associated with episodes of strike-slip and reverse rupture within the mainshock.

Spectra from the four stations within 1-2km of the Christchurch CBD, with phgas of 0.17g to 0.25g, approximate 500-year motions of the NZS1170 structural design standard for structures with periods from 0.3s to 1s (about 3- to 10-storey buildings), but lie below code motions at shorter periods. Strong peaks around 2.5s period with NS polarisation considerably exceed code spectra. These show amplification of motions by the several hundred metre deep gravels under Christchurch, but also indicate strong long-period content in the incoming waves because peaks at similar periods are not apparent in aftershock records. The associated large spectral displacements should have been demanding for long-period structures or structures responding beyond their yield levels.

Recorded motions from the eastern suburbs, including from the extensive liquefaction and spreading at the Hulverstone Road Pumping Station, provide important data for understanding the lateral spreading. Again, there are 2.5s peaks well in excess of 500-year motions that may be an important feature. Phgas and 0.3s to 1s motions are about 80% of 500-year design motions, and the motions are more deficient at periods below 0.3s.

SPATIO-TEMPORAL EVOLUTION OF AN AGGRADING TURBIDITE SYSTEM, PAKIRI, NEW ZEALAND

Sophie F. Milloy¹, Lorna J. Strachan¹, Heide Friedrich²

¹School of Environment, The University of Auckland

²Faculty of Engineering, The University of Auckland
smil126@aucklanduni.ac.nz

Interpreting a turbidite system is a complex task, as there are many different depositional elements involved. This study aims to reconstruct the turbidite system, represented by the type section of the Pakiri Formation, north of Auckland, New Zealand. The architectural elements represented within the outcrop are determined and their lateral and vertical relation to each other is assessed. To achieve this, detailed mapping and sedimentary logging was undertaken at a 1:100 scale. Eight lithofacies were defined from the section: structureless siltstones, crossbedded and laminated siltstones, fining upwards sandstones, massive sandstones, medium grained sandstones, several compound/multiple event beds, coarse sandstone with mega clasts, and reverse graded medium sandstones. All lithofacies were analysed in accordance with the Bouma Sequence and the turbulence of the flow that deposited them. The collected data was interpreted to represent a series of stacked lobes, channels and levees indicating that the system initially went through progradation, followed by aggradation. This resulted in a model that demonstrates the evolution of the turbidite system overtime, going from a distal setting dominated by lobes, to a more proximal, channel and levee dominated system.

VISITOR PERCEPTION OF NATURAL HAZARDS AT WHAKAPAPA AND TUROA SKI AREAS, MT RUAPEHU

C. Milnes, M.S. Brook, J.R. Mansvelt

School of People, Environment & Planning, Massey University, Palmerston North
m.s.brook@massey.ac.nz

Turoa and Whakapapa are ski areas located on the active volcano Mt Ruapehu, in the Central North Island of New Zealand. Mt Ruapehu is located within Tongariro National Park, one of the 14 National Parks administered by the Department of Conservation (DoC). Visitors to Whakapapa and Turoa ski areas encounter an array of hazards, including icy slopes, rugged cliffs and drop-offs, and as well as thousands of other mountain users. Natural hazards particular to Turoa and Whakapapa include the threat to human safety from lahars, ash falls, pyroclastic flows, and ballistic bombs due to the active volcanic nature of this mountain, as well as rock falls, snow avalanches and poor weather. Managing these hazards at Ruapehu is complex due to the number of factors involved. This dynamic site hosts visitors who are moderately experienced and prepared, but may be complacent about the danger to personal safety within these areas. This research investigated how the public perceives hazards at Whakapapa and Turoa ski areas at Mt Ruapehu, and identified the particular hazards to which visitors perceive they are exposed to. This was undertaken by questionnaire surveys with 400 public mountain users, and conducting semi-structured interviews with staff from Ruapehu Alpine Lifts (RAL) and DoC. DoC and RAL staff were interviewed in regard to their role as hazard communicators, focusing on the methodologies they use to convey safety messages to ski area visitors. A basic demographic profile of visitors to Whakapapa and Turoa ski areas was developed, and issues with communicating risk to ski area users in terms of their tendency to overestimate their abilities and take significant risk were identified. Indeed, visitors to Whakapapa and Turoa ski areas were shown to have only moderate awareness of hazards and a number of suggestions for ski area management are provided.

CONSIDERATIONS REQUIRED DURING THE ANALYSIS OF COMPOSITIONAL DATA

Gordon Miskelly¹, James Curran², Gareth Campbell¹

¹Dept. of Chemistry, The University of Auckland, Private Bag 92019, Auckland 1142.

²Dept of Statistics, The University of Auckland, Private Bag 92019, Auckland 1142.
g.miskelly@auckland.ac.nz

Many forensic classifications or discriminations involve multivariate comparisons of multiple measurements on two or more samples. Frequently, the variables being measured are elemental or chemical compositions. In such cases, it is important to select the correct statistical method for the comparison. The compositional data analysis framework championed by Aitchison has been recommended for such analyses. Application of this framework may be guided by background knowledge about the origins of samples, and how this affects chemical composition. Such comparisons need to have robust methods for variable selection and treatment of values below the limit of detection. These issues will be discussed, using as an example the identification of the source of New Zealand nephrite.

**LITHOSPHERIC STRUCTURE BENEATH MT. FUJI INFERRED FROM GRID SEARCH
INVERSION OF TELESEISMIC RECEIVER FUNCTIONS AND SURFACE WAVE
DISPERSION**

S. Miyabayashi¹, T. Igarashi¹, Y. Aoki¹, M. Takeo¹

¹Earthquake Research Institute, Univ. of Tokyo. 1-1-1, Yayoi, Bunkyo-ku, Tokyo,
Japan.
sawako@eri.u-tokyo.ac.jp

The average eruption rate of Mt. Fuji has been much larger than most other island-arc volcanoes in Japan. The typical eruption product from an island-arc volcano is andesitic, while Mt. Fuji has erupted basaltic products. To understand the magma-plumbing system, we have to reveal the structure below Mt. Fuji. Even though the region around Mt. Fuji is a very active tectonic zone, the seismicity below Mt. Fuji is quiet, resulting in little knowledge about the structure of the Philippine Sea (PHS) Plate below Mt. Fuji.

In this study, we estimate the structure below Mt. Fuji using a receiver function (RF) technique. This method is an effective tool in the seismic investigation of velocity gaps. First, we calculate RFs using multiple taper correlation (MTC) method and draw cross sections of the RF's amplitude. Then, we perform grid search inversion and construct the detailed structure below Mt. Fuji.

As a result, we find a high velocity boundary coming up from beneath the Moho-boundary of the surrounding PHS plate. The shape of this layer is similar to the low resistivity zone obtained from magnetotelluric data. We interpret this region as part of the magma-plumbing path of Mt. Fuji.

SOME ROCK SAMPLES FROM THE D'ENTRECASTEAUX ZONE AND RENNELL TROUGH

N. Mortimer¹, R.H. Herzer¹, B. Pelletier², J.M. Palin³, & P.B. Gans⁴

¹GNS Science, Private Bag 1930, Dunedin.

²IRD, RD BP A5, Nouméa CEDEX 98848 New Caledonia

³Dept. of Geology, Otago University, PO Box 56, Dunedin.

⁴Dept. of Earth Sciences, University of California, Santa Barbara, CA 93016 USA
n.mortimer@gns.cri.nz

The Coral Sea, South Rennell Trough, D'Entrecasteaux Basin, D'Entrecasteaux Zone, North and South Loyalty Basins and North Loyalty Ridge lie between New Caledonia, Vanuatu, Australia and New Guinea. They occupy an important position between the collided and telescoped arcs and basins of New Guinea and the still-open backarc basins north of New Zealand, and appear in Cretaceous-Cenozoic reconstructions. Much is inferred about their composition and origin but very little is actually known.

Three French cruises in the 1970s (GEORSTOM 1, 2 and 3NORD) recovered rocks from several locations in the region but little was published about them at the time. We recently obtained some of the GEORSTOM cruise rocks and are part way through a programme of petrological and geochronological (re)analysis.

Our preliminary interpretations of geochemical data confirm that all basalts from >2500 m water depth in the Coral Sea, North Loyalty Basin, Rennell Trough and D'Entrecasteaux Basin are similar in composition to those from mid-ocean ridges and/or wide back-arc basins. Occasional sodic intraplate lavas are present in the dataset, but (unlike closer to New Zealand) there are no shoshonites. Andesites with a clear subduction-related chemistry occur only on Bougainville Seamount; the remainder of the rocks from the D'Entrecasteaux Zone are MORB and/or BABB-like, perhaps suggesting an oblique convergence origin for this strongly-curved feature, (analogous to the Macquarie Ridge). Radiometric ages from the lavas will, we hope, considerably clarify their regional tectonic significance.

TAUHARA RESERVOIR FLUIDS – PREDICTIONS AND REALITY

E.K. Mroczek¹ & R. Smith²

¹GNS Science, Wairakei Research Centre, PB 2000, Taupo 3352.

²Contact Energy Ltd, Wairakei Power Station, PB 2001, Taupo 3352.

e.mroczek@gns.cri.nz

During 2006 - 2009 Contact Energy Ltd undertook an exploration well drilling programme at Tauhara Geothermal Field with seven new wells successfully drilled in the eastern part of the field with depths generally greater than 2000m and maximum measured temperatures just over 300°C. Based on compositions of pre-existing shallower wells which were drilled in the 1960s, the “parent fluid” temperature and composition of the Tauhara reservoir were inferred to be 260°C and 1600 mg/kg respectively (Henley and Stewart, 1983). Reservoir composition (chloride) and temperature (T_{quartz}) of the new wells in the central and northern areas were typically 1800 mg/L and 290°C respectively, significantly higher than the earlier predicted values. The southern-most well had different fluid chemistry with an inferred reservoir temperature of 290°C but more dilute at 1280 mg/kg and higher non-condensable gas content. At this time it is not clear if these characteristics are representative of the southern part of the reservoir.

The Tauhara well reservoir fluids all have a uniform Cl/B weight ratio of 56, which is quite distinct from nearby Wairakei (80) and Rotokawa (20, well RK4). Excluding the southern-most exploration well the Cl-enthalpy plot shows the reservoir fluids are related to each other by mixing with cooler acid-sulphate groundwater. However all wells lie on a mixing between “high CO₂ - low chloride” and “low CO₂ - high chloride” end members which has been observed at other TVZ geothermal fields (Giggenbach, 1995).

Henley, R.W., Stewart, M.K., 1983. JVGR, 15, 285-314.

Giggenbach, W.F. 1995, JVGR 68, 89-116.

REHABILITATION ISSUES FACED IN GEOTHERMAL POWER PLANT AT BACMAN

S. Naidu¹ & C.J.D. Fleming²

¹PB New Zealand Ltd, PO Box 3935, Shortland Street, Auckland.

²First Gen Corporation

The Bacman Geothermal Facility in the Southern Luzon Region of the Philippines has undergone condition assessment and the power plant will be rehabilitated to restore its generating capacity at Bacman I (Palayan) to 2 x 55MW and 1 x 20MW at Bacman II (Cawayan) by relocating the 1 x 20MW modular plant at Botong to replace the typhoon-damaged plant at Cawayan.

This paper discusses the issues faced in the condition assessment and selection of rehabilitation options for the power plants. The issues discussed are a mix of steam quality, plant location, plant operation, plant maintenance and environment. These have contributed to the current condition of the power plant and present an engineering challenge to the rehabilitation team to bring the plant back on line.

SEQUENTIAL ERUPTION OF ALKALINE AND SUB-ALKALINE MAGMAS FROM A SMALL MONOGENETIC VOLCANO IN THE AUCKLAND VOLCANIC FIELD

A.J. Needham¹, J.M. Lindsay², I.E.M. Smith², P. Augustinus², P.A. Shane²

¹School of Geosciences, Monash University, Melbourne, Australia.

²School of Environment, University of Auckland, PO Box 92019, Auckland.
andrew.needham@monash.edu

Rangitoto Volcano is the youngest and largest eruptive centre in the monogenetic intraplate Auckland Volcanic Field (AVF). The stratigraphy of Rangitoto pyroclastic deposits that have been preserved in swamps on nearby Motutapu Island and in Lake Pupuke on the mainland reveals that the volcano erupted twice; radiocarbon dating of 10 samples from the two tephra units in the swamps indicates eruption ages of 553±7 and 504±5 Cal years BP, for the lower and upper tephra layers, respectively. Geochemistry of the lava field and various scoria cones on Rangitoto Island itself reveals two distinct compositional groups: an alkaline olivine basalt group (that correlates geochemically with the lower tephra layer) and a group that is subalkaline and transitional to tholeiite (that correlates geochemically with the upper tephra layer). Based on this data, we infer that, following a phreatomagmatic vent-clearing phase, the early magmatic eruption of Rangitoto Volcano was Strombolian in character and produced an alkaline olivine basalt scoria cone and an associated thick ash deposit on nearby Motutapu Island. This was followed by a time gap of up to several decades, after which a second eruptive phase built the current summit scoria cone together with an encircling lava field. We suggest this later, sub-alkaline eruptive period was associated with the deposition of the thin upper tephra layer on Motutapu Island.

The two suites of Rangitoto samples are chemically quite distinct, and each is associated with a distinct parental composition. Trace element modelling indicates the alkaline and sub-alkaline parental melts could have been derived by ~1 and 6 wt.% partial melting of an anhydrous garnet peridotite source at ~80 and 65 km depth, respectively. The compositional range within each suite is similar, and can be explained by mainly olivine together with minor clinopyroxene fractionation within a relatively simple conduit system in which mixing and mingling were not important. Significant olivine fractionation (<25%) suggests that the magma may have spent some time in the upper conduit during ascent. This contrasts with a recently published model for the Crater Hill centre in the AVF, in which deep-seated fractionation of clinopyroxene followed by relatively rapid ascent to the surface has been invoked to explain the compositions seen there. The polycyclic nature of Rangitoto and in particular the reuse of the conduit system after a period of quiescence have implications for the concept of monogenetic volcanism. There are also implications for hazard assessment, such that when a future eruption occurs in the AVF, it will be necessary to consider the conduit a possible pathway for another eruption for up to several decades afterwards.

GRADUAL ERUPTION STYLE CHANGES REFLECTING THE GOVERNING ROLE OF EXTERNAL WATER AT MOTOKOREA ISLAND, AUCKLAND VOLCANIC FIELD (AVF)

K. Németh¹, L. McGee², I.E.M. Smith², S.J. Cronin¹ & J. Lindsay²

¹Volcanic Risk Solutions, Massey University, Palmerston North

²School of Environment, The University of Auckland, Auckland.
k.nemeth@massey.ac.nz

Internal (magmatic) and external (environmental) factors interact to govern eruption processes of basaltic monogenetic volcanoes. The small magma volumes (0.001 – 0.1 km³) of these volcanoes and relatively low mass-ejection rates mean that external environmental factors may play the most significant role in eruption manifestation. The base of the Motokorea succession is composed of an 8 m-thick tuff and lapilli tuff that is rich in accidental lithic fragments, mainly derived from the underlying siliciclastic Pliocene terrestrial and Miocene marine sediments, indicating the probable locus of fragmentation. Highly fragmented fine ash, cauliflower bombs, accretionary lapilli, low-angle cross-bedding, mega-ripple bedforms, as well as abundant glassy pyroclasts in this succession attest to its phreatomagmatic origin. The low vesicularity index of pyroclasts, showing thick vesicle walls and palagonitization are indicative of phreatomagmatic fragmentation. During the initial stages of eruption the vent area was broad. As it progressed, however, lower degrees of interaction occurred with external water and saturated sediment. This culminated in a phase of magmatic-gas driven fragmentation, producing a distinctive scoriaceous ash and lapilli fall unit with a NE-trending dispersal axis. The uppermost part of the pyroclastic sequence exposed a 15 m-thick succession of cm-to-dm thick accidental-lithic rich ash beds, alternating with coarse-scoriaceous ash and lapilli fall beds. This suggests either a regular alternation between wet and dry vent conditions, or that more than one locus of eruption was concurrently active. The "drying" of this eruption may reflect the developing stability of a vent location and conduit. The tuff ring succession is capped by scoria and spatter beds derived from several points within the tuff ring. Some of these vents produced a lava flow that forms a platform in the southern margin of the island. The resulting volcanic landform demonstrates the sensitivity of eruption style in such volcanoes to slight changes in magma-water interaction.

AUCKLAND IN PREHISTORY: VEGETATION, SETTLEMENT, AND ERUPTIVES FROM NEAR AND FAR

Rewi M. Newnham¹, **Maria Gehrels**², **David J. Lowe**³, **Paul Augustinus**⁴

¹School Geog., Environ. & Earth Sci., Victoria Univ. of Wellington, Box 600, Wellington

²School Geogr., Earth & Environ. Sci., University of Plymouth, Plymouth, PL48AA, UK

³Dept of Earth & Ocean Sciences, University of Waikato, Private Bag 3105, Hamilton

⁴School of Environment, University of Auckland, Private Bag 92019, Auckland

We present pollen and tephrostratigraphic records from Lake Pupuke, a maar crater within the Auckland Volcanic Field (AVF), that provides new insights into the area's natural history and volcanic hazards. The tephra record since ~2 ka includes two visible layers, Taupo tephra (AD 232 ± 5) and an alkaline phase of basaltic Rangitoto tephra (~AD 1400) from AVF. Five newly-identified cryptotephra were identified: Kaharoa tephra (AD 1314 ± 12) from Mt Tarawera, (at least) three andesitic correlatives of Tufa Trig Formation (Tf5, Tf6, Tf14) from Mt Ruapehu, and a sub-alkaline (to tholeiitic) phase of Rangitoto tephra (~AD 1450). The cryptotephra occurrences support a two-stage eruption history of Rangitoto volcano and show that Auckland has received ashfall from distant central North Island volcanoes more frequently in recent times than previously thought; Ruapehu may pose a particular threat. These results also enhance the region's tephrochronological framework, Kaharoa tephra being a critical datum for Polynesian settlement and a key isochron for Pupuke where ¹⁴C-dating has been problematic.

The tephrostratigraphic relationships provided independent-age estimates of the earliest palynological evidence for human settlement in Auckland at ~AD 1320. The pollen record, spanning the last ~800 years, provides a higher-resolution coverage of the prehistoric era than any obtained previously for Auckland. Four distinct phases are recognised. 1. Prior to the Kaharoa eruption, the vegetation was predominantly northern conifer-broadleaf forest with kauri, rimu, rata, and pohutukawa as dominant trees. 2. Minor but sustained disturbances are manifested soon after Kaharoa deposition as increased bracken spores and charcoal – classic indicators of forest clearance by fire. 3. More pronounced forest clearance by burning is evident following the main alkalic Rangitoto eruption, suggesting the preceding first few decades of human impact had been comparatively benign. 4. Yet stronger impacts are evident for the European era marked by introduction of exotic pollen.

OLIGOCENE ARC VOLCANISM IN NEW CALEDONIA

K. Nicholson & C. Rickey

Department of Geological Sciences, Ball State University, Muncie, IN, USA, 47306
knichols@bsu.edu

The Nouméa Basin in New Caledonia, forms a narrow band, roughly 30km by 60km, that extends from the city of Nouméa north-westward towards La Tontouta. The Nouméa Basin represents a sequence of late Cretaceous basalts, rhyolites and marginal marine sedimentary typical of continental margin volcanic arcs. In the southern corner of the Nouméa Basin, in the Bay of La Conception, there are two quarries both of which extract basaltic andesitic rocks.

At La Conception quarry the lavas form an apparent eruption center. Flow directions are random towards the center and develop a definable direction radiating outwards. At the Pont des Français quarry (~0.5 km to the north east) the units form shallow dykes intruding sediments of the Nouméa Basin. Chemically both sets of lavas are identical and are herein referred to as the Conception lavas.

The Conception lavas are basaltic-andesite lavas, containing plagioclase (albite) and pyroxene (diopside), with minor magnetite and apatite. Alteration and metamorphism is weak and non-pervasive with <5% chlorite, prehnite and pumpellyite predominately filling veins and open spaces. Chemically the Conception lavas are typical of arc-related basaltic andesite lavas with elevated (100x) light rare earth element (REE) abundances relative to C1 chondrite, and 10x C1 chondrite abundances of the heavy REE. The lavas are also characterized by elevated large ion lithophile elements (100x) and depleted high field strength elements relative to average MORB values. More specifically the Conception lavas have a strong negative Nb anomaly with Nb/Th ratios characteristic of formation in an arc environment. The geochemical data suggest a slightly enriched MORB source for the lavas. Comparing the data to other systems suggests a similarity to the Marianas. Recent whole rock Ar/Ar dating of these rocks clearly illustrates that these lavas are Oligocene in age (28.5 to 29.5 Ma).

**THE GEOFORENSIC INTERNATIONAL NETWORK:
A DOSE OF GIN FOR THE IUGS**

D.C. Nobes¹ & L.J. Donnelly²

¹NZ Member of GIN, Department of Geological Sciences, University of Canterbury.
david.nobes@canterbury.ac.nz

²Officer of IUGS-GEM GIN, Wardell Armstrong, Greater Manchester, UK.
ldonnelly@wardell-armstrong.com

In the last decade, forensic geoscience (geoforensics) has experienced a renaissance around the world. There have been at least 10 international meetings and conferences, 5 books published, and numerous research papers and magazine articles.

In 2009, the Geosciences for Environmental Management (GEM) committee of the International Union of Geological Sciences (IUGS), approved the formation of the special interest Working Group on Forensic Geology. As a consequence, the Geoforensic International Network (GIN) was also established. The aim of the working group and GIN is to develop forensic geoscience internationally and promote its applications. GIN brings together forensic geoscientists from around the world, who work in academia, consultancy, the police, regional and national networks. Regional networks frequently have international links and members; however they are not inherently international in scope, nor do they necessarily have international sanction.

GIN's objectives are (GEM News, August 2010):

- "to collate and disseminate data and information on forensic geology applied to policing and law enforcement, criminal and civil investigations";
- "to promote international meetings, seminars and conferences";
- "to develop an international 'Working Group' whereby each 'Member' will act as a principal contact in their respective country for the collation and dissemination of information on forensic geology";
- "to develop a 'Steering Group Committee' to act as principal advisors and collaborators";
- "to collate and review any existing documentation and publications in forensic geology"; and
- "to produce a document endorsed by the Steering Group Committee and Members to be called 'A Guide to Forensic Geology'."

The GIN Working Group has a 3 – 4 year plan with several tasks which include developing international contacts in forensic geosciences, a web site to facilitate comment and interaction amongst the international forensic geoscience community, and producing a document called "A Guide to Forensic Geology".

**IMPACT OF HUMAN ACTIVITIES ON SEDIMENTATION IN THE BAY OF ISLANDS:
RESULTS FROM OCEAN SURVEY 20/20**

**S. D. Nodder¹, A. Swales², M. Gibbs², H. Bostock¹, J. Mountjoy¹, A.-L. Verdier,
D. Mole,³**

¹NIWA, Private Bag 14-901, Kilbirnie, Wellington.

²NIWA, PO Box 11115, Silverdale, Hamilton.

³ Land Information New Zealand, Private Box 5501, Wellington.
s.nodder@niwa.co.nz

The Bay of Islands, Northland, is an iconic tourist destination and the historic birthplace of New Zealand (Aotearoa). Polynesian explorers arrived about 1300 AD, and extensive forest clearance had occurred in the hinterland of the bay by the time of Cook's visit in 1769. Such deforestation continued, following European settlement in early 19th Century, until the present day when the landscape became dominated by pastoral agriculture and more recently horticulture and exotic and regenerating native forests. As part of the Ocean Survey 20/20 project, instigated in 2008, local interest groups identified sedimentation as a primary stressor on the coastal environment. Accordingly, an extensive survey of the sediment distribution and characteristics, including sedimentation rates and sources, was implemented in 2009-10.

The bathymetry and substrates on the sea-floor of the bay and adjacent shelf were mapped using ship-mounted multibeam echo-sounders, and sediment coring. Physical and biogeochemical properties of surface sediments showed that the shallow inlets of the bay are dominated by organic-rich, low carbonate muds that become sandier, more carbonate- and less organic-rich out onto the shelf. Shelly gravels predominate around many of the headlands and capes, and in shallow, land-constricted areas swept by strong tidal currents. Sedimentation accumulation rates (SAR) over the last 150 years, determined using radio-isotopes, were highest in the inlets and diminished on the shelf (~4-5 mm y⁻¹ to 2-3 mm y⁻¹). Sediment source data, determined using compound-specific stable isotopes of carbon, indicated that ~80% of the sediment in the bay was derived from the erosion of pastoral lands, although this varied depending on individual catchment land-use. Comparison of SAR with high-resolution geophysical data from the main depocentres show that, based on a long-term SAR over the last 10 000 years of 23 000 t/yr, historic human activities have resulted in a 20-fold increase in sediment accumulation in the bay.

WHERE ARE THE EARTHQUAKES? ACTIVE FAULTS AND EARTHQUAKES EAST OF THE ALPINE FAULT

Richard J Norris

Department of Geology, University of Otago, PO Box 56 Dunedin
richard.norris@otago.ac.nz

The Alpine Fault forms the major plate boundary structure in the South Island. Estimates of late Quaternary slip rates range from 23 to 27 mm/yr with various degrees of uncertainty. Despite uncertainty, it seems clear that about 10 mm/yr is required to be accommodated on structures other than the Alpine Fault. The distribution of earthquakes and known active faults, together with geodetically measured strain, indicate that, in the central South Island, most of this displacement occurs east of the Alpine Fault. Mapped active faults east of the Alpine Fault have an average length of 25 km and a typical event displacement of 1-3 m, corresponding to a c. M6.7 earthquake. For the 300 km from Hokitika to Milford Sound, 12 average faults laid end to end are required, accumulating a total of 10 m in a 1000 yr period, or a total of 60 events of around M6.7. Only c.10 events in a 1000 year period are expected from estimated return periods of known active faults. The total expected moment release over the last century, however, is similar to that calculated from recorded earthquakes, most of which did not occur on mapped faults nor leave a surface trace. Faults within the Pacific plate in South Island, I suggest, unlike the Alpine Fault, do not have deep creeping mylonite zones beneath them, but rather are reactivated zones of weakness in the upper crust that rupture in response to distributed deformation above a ductily deforming lower crust. Many show periods of activity punctuated by long periods of quiescence. They do not have meaningful slip-rates. Any pre-existing fault could be reactivated. Thus detailed seismic hazard analysis based on recognized active faults is difficult.

UNDERSTANDING CULTURAL LANDSCAPES

A. Olsen

NTST, PO Box 93, Matata, RD4
obsidian03@xtra.co.nz

In order to fully understand the concepts of manawhenua (ahi kaa) and tangata whenua one must have regard to the cultural landscape. Recorded and un-recorded archaeological sites are only one layer of the cultural landscape, and are not “the” cultural landscape. Waahi Tapu (sacred sites), Waahi Whakahirahira (sites of significance) and Waahi Taonga (treasured sites) are amongst some of the key indicators of the wider cultural landscape. Manawhenua, the ability to walk ones rohe and name the places and recite the korero (history) back to “discovery” is primacy. While other iwi may have an interest/s, in a rohe it may not give them Manawhenua. Tikanga Maori (principles) formed the basis of the consultation methodology used with all the iwi with interests in this area. Therefore tension arises between the Maori world and western science over the application of RMA concepts to landscape. The viewing and valuing of landscape varies considerably between the cultural paradigms, of Maturanga Maori and Western Science. The intrinsic belonging of tangata whenua to these landscapes stems from whakapapa not from some cadaster outlining the value extent and ownership of land. The application of kaitiakitanga and its accompanying responsibilities require an intergenerational temporal perspective that views landscape as a weaving together of history and occupation that is both dynamic and integrated. It is not the place for Archaeologists to determine either the history of relevance of that landscape from a tangata whenua perspective. What is important is at least an attempt to preserve the integrity of this cultural association and to further acknowledge that tangata whenua expertise in this field is both relevant and valid.

PEST FOR GEOTHERMAL MODEL CALIBRATION

J.B. Omagbon¹ & M.J. O'Sullivan²

¹Energy Development Corporation, Fort Bonifacio, Taguig 1634, Philippines.

²The University of Auckland, Auckland, New Zealand.

omagbon.jb@energy.com.ph

PEST is a nonlinear parameter estimation and uncertainty analysis software package that can be used to estimate parameter values for any numerical models including those used in the geothermal industry. This paper demonstrates the application of the automated parameter optimization software PEST in conjunction with TOUGH2 for geothermal model calibration. Different parameter estimation modules for inverse modelling techniques included in the PEST package was used to estimate various parameters of the reservoir model. Uncertainties of the obtained parameters were evaluated using techniques which were likewise integrated in PEST. Model predictions were then conducted using the calibrated model. Probabilistic analysis was implemented in the model predictions to quantify the uncertainties related to the forecasts made. Results obtained during calibration yielded very good improvement in the model matches. In addition, application of probabilistic analysis provided valuable information in quantifying model uncertainty and forecast integrity. This proved that PEST is a useful tool in the calibration process and can serve as a good alternative for the more common inverse modelling software such as ITOUGH.

RWANDA GEOTHERMAL RESOURCES EXPLORATION AND DEVELOPMENT STRATEGY

S.A. Onacha^{1,2}, U. Rutagaram², T. Uhorakeye², J.N. Namugize, & C. Irabatura²

¹Institute of Earth Science and Engineering, University of Auckland, Auckland

²Ministry of Infrastructure (MININFRA), Rwanda

stephenonacha@gmail.com

Rwanda which is part of the “ring of fire” hosts two high potential zones for geothermal energy exploitation: The two zones are found in the western region (Gisenyi, Karisimbi, Kinigi) associated with volcanoes and the southern region (Bugarama) associated with faults in the East African Rift. This is an area of complex geological and tectonic structures due to intense multiple volcanic and tectonic events. NE and NW trending faults and fractures on exposed basement rocks are the dominant surface structures. The volcanic and tectonic events are postulated to have generated high heat flow and geothermal activity. Some of the fractures also control the occurrence of mineralized zones which were formed by circulation of hydrothermal fluids. Evaluation of mineralization in the mines is therefore important in understanding the structures that control fluid flow in the basement which is covered by recent lava flows.

Based on reconnaissance surface studies, the western region has been divided into three areas of Gisenyi, Karisimbi and Kinigi that can be developed as separate geothermal prospects. The three areas can further be divided into smaller fields that can either be developed by one company or several companies provided that an adequate geothermal resource management act is put in place. It is evident from available information that Rwanda has areas that have low-temperature geothermal resources that can also be utilized for both power generation and indirect uses. Low temperature areas may be found on the margins of the western and southern high temperature regions.

The major challenge is therefore to find the best targets to develop geothermal resources in a cost effective and timely manner. The Government of Rwanda (GoR) has therefore put in place a strategy for exploration and development to accelerate geothermal development. An important part of the development strategy is to reduce the perceived risks in developing geothermal resources by conducting studies that can lead to locating high potential regions. The immediate goal is to carry out surface exploration, exploration drilling and if possible early generation to prove that geothermal energy is a viable source of energy. With extensive exploration and appraisal drilling geothermal can contribute more than 20 MWe in the short term and over 300 MWe in the long term. This fits into the mission of the energy sector which is to create favourable conditions for the provision of safe, reliable, efficient, cost-effective and environmentally appropriate energy services to all sectors of Rwanda economy on a sustainable basis.

X-RADIOGRAPHS REVEAL HIGH-RESOLUTION STRATIGRAPHY ON THE MUDDY AND ENERGETIC POVERTY BAY CONTINENTAL SHELF

A. Orpin¹, JP Walsh², R. Corbett², A. Ogston³, R. Hale³, J. Kiker², J. Moriarty⁴

¹NIWA, Private Bag 14-901, Wellington 6241

²Dept. of Geological Sciences, East Carolina University, Greenville, NC 27858, USA

³School of Oceanography, University of Washington, Seattle WA 98195, USA

⁴Virginia Institute of Marine Science, College of William and Mary, Gloucester Pt., VA 23062, USA

a.orpin@niwa.co.nz

The Poverty Bay continental margin contains a remarkable Holocene sedimentary archive of environmental change. Landscape sediment yields in the muddy Waipaoa River catchment today are among the highest on earth; the product of rapid tectonic uplift along the convergent plate boundary, easily erodible lithologies, a vigorous maritime climate, and deforestation. Accordingly, terrigenous inputs dominate the marine sediment record on the adjacent Poverty Bay continental margin, which retains signals generated by perturbations to terrestrial and marine conditions occurring over a range of timescales. The resulting stratigraphy records variations in the frequency and magnitude of sedimentary events. Significant advances in the understanding of sedimentation throughout the Waipaoa Sedimentary System have been afforded through the MARGINS Waipaoa Source-to-Sink initiative, but the balance of processes that drive sediment dispersal, deposition, and erosion on the energetic continental shelf remains largely unknown. At the heart of a current MARGINS project is the fundamental goal of determining how the shelf sedimentary record is produced by diverse processes operating across a range of timescales. To date, around 150 precision multi-cores from the Poverty shelf have been slabbed for X-ray analysis using a portable digital imaging system and subsampled for radiochemical tracers Pb-210 and Be-7. X-radiographs provide invaluable insights into the architecture of sedimentary structures preserved in cores and an excellent diagnostic tool for identifying event beds. Provisional comparison of X-radiographs and radioisotope data at reoccupied core sites over nine months suggests that changes occur over seasonal timescales. This approach raises significant philosophical questions about the fidelity and completeness of the geological record, which is hypothesized to increase with water depth as fluvially-deposited sediment is overprinted with a marine signature.

RECOVERY FACTOR FOR WAIRAKEI

M.J. O'Sullivan¹, W.I. Mannington², K. Brockbank² & A. Yeh¹

¹Department of Engineering Science, University of Auckland, Private Bag 92019, Auckland 1142, New Zealand.

²Contact Energy Limited, Wairakei Power Station, State Highway 1, Private Bag 2001 Taupo 3352, New Zealand
m.osullivan@auckland.ac.nz

The standard method for estimating the size of a geothermal resource when little field data are available is to carry out a stored heat calculation. This involves dividing the reservoir up into a few zones, each with a characteristic average temperature. The initial heat content of each zone is calculated and then summed to give the total initial heat in the reservoir. Then a final temperature is assumed (say 180degC) and a final heat content is calculated. The difference between the two gives the maximum heat available for production which is then multiplied by a recovery factor to give the recoverable heat, which in turn can be used to size a power plant. There is considerable uncertainty in the choice of the recovery factor. Often a statistical approach is adopted with a probability distribution assigned to the recovery factor and the other parameters and a Monte Carlo approach is used to size the plant.

In the present work the experience from 50 years of production from Wairakei is used to retrospectively determine what value of recovery factor would have been appropriate in 1950 to estimate the average MWe output from Wairakei for the past 55 years.

First a very approximate estimate of the volume of the reservoir is used and then the natural state results from our computer model are used to narrow down the estimates of volumes and temperatures thus assigning most of the uncertainty to the recovery factor alone. The @RISK software is used to carry out a Monte Carlo stored heat calculation. It turns out that the recovery factor required is close to 1.0, much higher than that normally used.

GEONET: MONITORING NEW ZEALAND'S NATURAL HAZARDS

S. Page

GNS Science, 1 Fairway Drive, Avalon, Lower Hutt
s.page@gns.cri.nz

New Zealand is a country in motion. We face earthquakes, volcanoes, tsunamis, landslides and geothermal activity. In many places where you live and work these hazards have the potential to cause devastating social and economic loss.

Operated by GNS Science and funded by the New Zealand Earthquake Commission (EQC), the GeoNet Project was set up in 2001 to provide real-time monitoring of these hazards. The project uses nationwide networks of seismograph, GPS and strong-motion accelerographs to collect data on New Zealand's strain and deformation patterns, earthquakes, volcanoes, and a growing network of tsunami gauges collect measurements of sea-level fluctuations

The completion of these networks in the last nine years has improved the timing and accuracy of incoming data, and the project's focus has now shifted to the extension of regional seismic and GPS networks, the growth of the regional tsunami gauge network and the development of data products to promote better uptake of this valuable resource.

The data collected by the New Zealand GeoNet Project are fundamental to a better understanding of the natural hazards faced by this country and in turn, this knowledge will improve their detection and management. It is hoped that the dissemination of accurate and timely information by GeoNet will aid planning and community preparation before a disaster strikes, and facilitate effective emergency responses afterwards, speeding the subsequent recovery of affected communities.

PALAEOENVIRONMENTS OF THE EOCENE KAIATA FORMATION, WEST COAST

R. Pearson & Catherine Reid

Dept. of Geological sciences, Uni. of Canterbury, PB 4800, Chch 8140
renee.pearson@pg.canterbury.ac.nz

The Kaiata Formation is a variable marine unit of calcareous brown mudstone and muddy fine sandstone, of Late Eocene to Earliest Oligocene age, containing a range of fossils, abundant foraminifera and includes algal reef and shoreline sand deposits. The unit outcrops at several localities along the northern West Coast of the South Island and was deposited in the elongate, extensional, tectonically controlled Paparoa Trough. Currently there is little knowledge of the palaeoenvironments represented by the Kaiata Formation and the geometry and evolution of the depositional basin remains largely undefined.

Preliminary results show evidence for shallow water shelf sequences with a pattern of deepening then shallowing in a semi-enclosed embayment, at outcrops at Woodpecker Bay (near Fox River mouth) and Gibson's Beach (at Cape Foulwind). The Eocene-Oligocene boundary has been recognised biostratigraphically in the upper part of the section at Gibson's Beach in previous studies. Further work should more precisely locate this boundary and establish a similar boundary in the Woodpecker Bay section. At Cape Foulwind is a well developed algal limestone, currently quarried for use in cement production, indicating shallow water conditions on a topographic high or very shallow shelf. To the north, at Waimangaroa, coarse beds of the Torea Breccia Member inter-finger with typical Kaiata mudstone, suggesting an uplifted ridge as a source of sedimentary gravity flows. Discontinuous, faulted outcrops near Seddonville hosting no foraminifera and abundant pyrite suggest anoxic bottom water and the dissolution of calcite.

Foraminiferal results are being analysed for biostratigraphic and environmental interpretation to be integrated with sedimentary facies analysis, in order to form a model resolving the biostratigraphy and palaeogeography of the Kaiata Formation, and identify palaeoenvironmental changes through out the evolution of the basin.

NUMERICAL SIMULATIONS TO ASSESS GEOLOGICAL CONTROLS ON AN ACTIVE HYDROTHERMAL SYSTEM: MASAYA VOLCANO, NICARAGUA

S.C.P. Pearson¹, C.B. Connor², W.E. Sanford³, K. Kiyosug², J.A. Saballos² & H. Lehto²

¹GNS Science, Wairakei Research Centre, Private Bag 2000, Taupo, New Zealand.

²Dept. of Geology, University of South Florida, 4202 E. Fowler Ave, Tampa, USA.

³U.S. Geological Survey, 12201 Sunrise Valley Drive, Reston, Virginia, USA.

s.pearson@gns.cri.nz

Fumaroles are a surface reflection of the interaction between groundwater and geothermal heat at depth. Variations in fumarole location or temperature may therefore be related to changes in groundwater and/or heat sources. However, to correctly interpret changes in surface manifestations in terms of changes in the hydrothermal system, geological controls on fluid flow must be understood. At Masaya volcano, Nicaragua, the only fumarole zones are observed along a fracture on one flank of the volcano. TOUGH2 modelling shows that these distinct fumarole zones can result from convection in the saturated zone, with constant and uniform injection of hot fluid at depth at 0.006 kg/s/m². Relatively high fracture permeabilities of around 10⁻¹⁰ m² are suggested by the models.

Magnetic profiles across the flank fracture show an anomaly of up to 2300 nT that corresponds extremely well with the topographic offset of a localised fault system. CO₂ and temperature profiles suggest that these faults form a boundary to flow. TOUGH2 models of the vadose zone show that with relatively impermeable faults, elevated fluid flux occurs in the hanging wall of the faults, and flow is inhibited in the footwall of the faults. A range of permeability and injection conditions can recreate the observed surface temperatures. However, horizontal layers determined from the magnetic data are not supported by the modelling, suggesting that there is not a strong permeability contrast between the layers. These models reveal that it takes fluids a minimum of 13 hours to travel from the watertable to the surface, but more likely days to months. Local geological structures like faults are a strong factor in the location and response of fumaroles to source variations, and numerical modelling including these features can improve understanding of how they affect the hydrothermal system, and provide constraints on subsurface features that cannot be measured.

VARIATIONS IN FUMAROLE TEMPERATURE RELATED TO VOLCANIC ACTIVITY AT MASAYA VOLCANO, NICARAGUA

S.C.P. Pearson¹ & C.B. Connor²

¹GNS Science, Wairakei Research Centre, Private Bag 2000, Taupo, New Zealand.

²Dept. of Geology, University of South Florida, 4202 E. Fowler Ave, Tampa, USA.

s.pearson@gns.cri.nz

Flank fumaroles are a direct result of the interaction between groundwater and magma, and therefore have good potential for monitoring volcanoes. We continuously monitored fumarole temperatures at Masaya volcano, the most persistently active volcano in Central America, for three years. These measurements revealed rapid fluctuations in fumarole temperature in response to volcanic activity. For example prior to formation of a small summit lava lake temperatures increased by up to 5°C in a fumarole zone 4 km down the flank of the volcano. During changes in volcanic activity there was also a distinct structure to the temperature signal of the fumarole gases. There were four periods where both surficial volcanic activity and fumarole temperature changed, each comprising of 10-15 cycles of rapid temperature fluctuations over 10 days. Rainfall also showed a significant, albeit imperfect, correlation with these signals. The frequency spectrum proved to be an extremely useful tool in identifying the beginning and end of the anomalous episodes.

We hypothesize that the rapid response of fumarole temperature to volcanic activity is due to increased flow of gas through the vadose zone, possibly caused by changes in the subsurface pressure distribution. TOUGH2 models show that an abrupt injection of hot gas, at approximately 100 times background rates, can cause the rapid increase in temperature observed initially at the fumaroles during volcanic activity. A decrease in hot fluid injection rate can explain the gradual decrease in temperature afterwards. Mixing with surrounding vadose-zone fluids can result in the consistent and abrupt decreases in temperature to background level that we measured at the end of each cycle. Modelling shows that variations in permeability, groundwater level or fluid temperature alone cannot create the distinct signal observed. Therefore changes in gas flux prior to volcanic activity may result in fumarole temperature variations that can be detected at the surface even quite distal to the active crater.

FORECASTING THE CONSEQUENCES OF THE FAILURE OF THE EASTERN RIM OF CRATER LAKE, MT RUAPEHU.

E. Phillips, J. Procter, G. Lube & S. Cronin

Volcanic Risk Solutions, INR, Massey University, Private Bag 11222, Palmerston Nth.
E.Phillips@massey.ac.nz

The eastern rim of Crater Lake, Mt Ruapehu consists of a stratigraphic sequence of intercalating volcanoclastic diamictons, pyroclastics and lavas, some of which are highly hydrothermally altered. This rim is under outward pressure from Crater Lake and constitutes one of the steepest parts of the active volcano. Its sudden failure could involve up to 40 million m³ of rock material, almost certainly generating a debris avalanche and/or, a break-out lahar up to 9 times the size of the March 2007 event. Similar failures of hydrothermally altered flank materials on this side of the volcano have already occurred (c. 4600 yrs Mangaio Fm.). A quantitative hazard and risk analysis of this scenario has never been undertaken, despite ongoing hydrothermal alteration and considerable sapping of both the inside and outside of the rim from explosive eruptions and base surges during the 1995/1996 and 2007 eruptions.

New stratigraphic data was integrated with existing high-resolution topographic information and aerial photography to produce a three-dimensional model of the eastern rim complex. The new 3D geological and structural model highlights the distribution of contrasting stratigraphic sequences and the distribution of those units with the largest degree of alteration. This information can be used as a first step towards defining the likelihood of different failure volumes and geometries to be tested in numerical hazard simulations.

Combining the 3D geological model with a numerical model of collapse and run-out a quantitative scenario-based hazard forecast for partial or full collapse of the crater rim and subsequent events was determined. We apply granular continuum computational modelling techniques to simulate a range of initial collapse volumes and locations resulting in single- and multiple-event debris avalanche scenarios. Simulated data of flow run-out, inundation, diversion, velocity and mass transport are analysed to identify the resulting hazards for the Whangaehu and Tongariro River catchments.

NEW PERSPECTIVES ON THE 1954-75 SUMMIT CONE OF NGAURUHOE VOLCANO

A. Pittari¹, J.B. Krippner¹, R.M. Briggs¹ & G.N. Kilgour²

¹Dept. Earth & Ocean Sciences, University of Waikato, Hamilton.

²GNS Science, Wairakei Research Centre, Taupo.

apittari@waikato.ac.nz

Summit vent complexes on composite cones are transient and undergo modifications in morphology and stratigraphy over their eruptive history. The most recent construct within the summit crater of Ngauruhoe is a 40 m high basaltic andesite scoria cone, with an 80 m deep inner crater, formed from 1954 to 1975. Recent field observations and textural and component studies have resulted in a revised stratigraphic framework and improved understanding of the processes of the Ngauruhoe summit cone evolution.

Exposures of the pre-1954 sub-crater occur near the crater floor of the present scoria cone and are hydrothermally altered variably agglutinated lapilli agglomerate. The overlying scoria cone succession is composed of, from base to top:

- a 28 m thick scoria lapilli and bomb facies association of (a) diffusely stratified, inward-dipping lower facies, (b) laterally discontinuous, agglutinated to coherent facies, and (c) well stratified, outward-dipping upper facies; representing the growth of an early scoria cone by strombolian fall during 1954;
- a 0.8 m thick thinly bedded, scoria and dense angular lapilli and ash facies association emplaced by pyroclastic fall and density currents during predominantly vulcanian activity, observed in late 1954-5, 1972-3 and/or 1974-5; and
- a 10 m thick massive, scoria and dense angular lapilli, bomb and block facies, with an agglutinated lower zone, which also drapes the outer slopes of the pyroclastic cone and steep inner crater slope; much of which was accumulated by proximal fall from fire fountains at the base of a subplinian eruption plume during the 19 February climactic phase of the 1975 eruption.

The 1954-75 scoria cone was constructed predominantly by fallout from strombolian and subplinian-modified fire fountains. Lava (1954-5) and pyroclastic flow (1974-5) deposits, which occur on the northwestern slopes of Ngauruhoe, constitute a greater eruptive volume, but have contributed very little to summit cone growth.

LONG-LIVED ISOTOPES: TRACKING CHANGES IN PALEO-OCEAN CIRCULATION AND ICE SHEET DYNAMICS OF THE ANTARCTIC-SOUTHERN OCEAN SYSTEM

A.A. Plant¹, J.A. Baker¹, L. Carter², I. Graham³, M.R. Handler¹, D.G. Ulfbeck⁴

¹SGEES, Victoria University of Wellington, P.O. Box 600, Wellington

²ARC, Victoria University of Wellington, P.O. Box 600, Wellington

³GNS Science, PO Box 30-368, Lower Hutt 5040

⁴STARPLAN, Natural History Museum of Denmark, Copenhagen, Denmark
plantamy@myvuw.ac.nz

The daughter products of long-lived isotope systems $^{176}\text{Lu} \rightarrow ^{176}\text{Hf}$, $^{147}\text{Sm} \rightarrow ^{143}\text{Nd}$ and $^{238,235}\text{U}, ^{232}\text{Th} \rightarrow ^{206,207,208}\text{Pb}$ have seawater residence times that are shorter than ocean mixing time-scales. Hence, these tracers in seawater record changing source inputs (continental and hydrothermal) into the ocean through changes in the intensity and style of continental weathering, as well as changes in ocean circulation. Isotopic signatures for these systems in the paleo-ocean can be recovered by analysis of authigenic ferromanganese [Fe-Mn] sediments (nodules/crusts; Fe-Mn oxyhydroxide coatings on pelagic sediments). We have measured Hf-Nd-Pb isotope ratios in two Fe-Mn nodules from the Bollons nodule field southeast of New Zealand (52°58.2'S 174°55.3'E, 4600 mbs) spanning an age range from 15-0 Myr (^{10}Be dates). The nodules come from the point where the Antarctica Circumpolar Current (ACC) enters the Pacific Ocean in concert with the Deep Western Boundary Current, but with the more energetic ACC dominating the deep circulation. Nd isotope ratios show little variability ($\epsilon\text{Nd} = -8.4$ to -7.6) suggesting that the amount of continental input from Antarctica into the ACC has changed little over the past 15 Myr. However, Hf isotope ratios show substantial differences ($\epsilon\text{Hf} = +7.1$ to $+3.2$) with high and variable values from 15-10 Ma, followed by a sharp decrease to the lowest values at 10 Ma, which have remained relatively low to the present-day except for a small increase during the Pliocene. The large decoupled variations in Hf-Nd isotopes are interpreted to track the development of permanent Miocene ice sheets on Antarctica, which through mechanical weathering more efficiently destroy zircon crystals to release unradiogenic Hf with low ϵHf into the ACC during periods of more intense and extensive glaciation. In addition to Hf-Nd-Pb isotopes, trace element analysis of the Fe-Mn nodules is underway and these results will be presented and discussed to examine if any secular changes in ocean trace chemistry are recorded over the past 15 Myr.

CHEMICAL AND PHYSICAL CHANGES IN ANDESITE ROCK DURING HYDROTHERMAL ALTERATION: INSIGHTS FROM THE ROTOKAWA GEOTHERMAL FIELD, NEW ZEALAND

A. Pochee¹, P.R.L. Browne², D.M. Gravelly³, T. Powell⁴, I.E.M. Smith⁵ and A.J.Rae⁶

^{1&2}IESE, University of Auckland, Private Bag 92019, Auckland.

³Geological Sciences, University of Canterbury, PB 4800, Christchurch.

⁴Mighty River Power, 283 Vaughan Rd, Rotorua, 3010.

⁵Geology Programme, School of Environment, UoA, Private Bag 92019, Auckland.

⁶GNS Science, Wairakei Research Centre, PB 2000, Taupo.

where

The Rotokawa geothermal system, about 10km from Taupo in the North Island of New Zealand, is partly hosted by the Rotokawa Andesite between depths of approximately 1.2 -2.8km. Cores from the andesite show varying degrees of hydrothermal alteration. We have quantified chemical and physical changes within the unit as a result of hydrothermal alteration by comparing rock samples with different intensities and ranks of alteration.

XRF analyses show that alteration has typically resulted in a slight loss of mass ($\leq 15\%$), mainly lost as Si, which was liberated during dissolution or replacement of primary minerals and removed from the alteration site by the geothermal fluid. The other major elements (Na, K, Fe, Mg, Ca) experienced more subtle gains or losses and typically were only slightly mobile during alteration. S and C in places were slightly added to the andesite by the geothermal fluid and additions in these elements are associated with deposition of pyrite and calcite respectively. Trace elements show limited mobility, the main changes being in Sr, Rb and Ba. Sr additions and losses commonly mimic those of Ca while Ba and Rb tend to follow K.

Altered samples have higher effective porosity (3-18%) than the least-altered samples (<2%) and lower bulk densities. Calculated volume and mass losses are broadly proportional, consistent with a leaching of mass during alteration leading to reduced bulk density and increased porosity in the altered rocks.

SEM and petrographic observations show that porosity has increased as a result of alteration, through sub-microscopic pore spaces including secondary mineral grain boundaries, dissolution voids and spaces between loosely spaced secondary minerals. The contribution of this low to moderate porosity ($\leq 18\%$) to large scale permeability within the geothermal system is unknown but it may be less significant than that of fracture pathways, for example along joints and faults.

**LOW ENTHALPY GEOTHERMAL ENERGY RESOURCES FOR RURAL MĀORI
COMMUNITIES – TE PUIA SPRINGS, EAST COAST, NORTH ISLAND NEW ZEALAND**

Pia Pohatu¹, Tui Warmenhoven¹, Andrew Rae^{2*}, Diane Bradshaw²

¹ He Oranga mo nga Uri Tuku Iho Trust, 20 Barry Avenue, Ruatorea 4032, New Zealand

² GNS Science, Wairakei Research Centre, Private Bag 2000, Taupo, 3352, New Zealand

* a.rae@gns.cri.nz

Māori have a long association with New Zealand's natural environment. This association is based on knowledge that has built up over time through centuries of interaction with the natural world, and includes use of low enthalpy geothermal resources within iwi/Māori communities. A "low enthalpy" geothermal resource is considered one where heat energy is generally <150°C. We explore the knowledge that existed within Māori communities pertaining to traditional uses, and also what technical capability and capacity these communities have or require to utilise energy from this resource. A review of the scientific data to date is also provided. "Rural Māori Communities" refers to those living in Te Puia Springs (an area containing a low enthalpy geothermal resource) and having a cultural relationship with, or significant interest, in the geothermal resource.

**MASS TRANSPORT ACTIVITY IN DEEP SEDIMENTARY SYSTEMS
ALONG THE NORTHERN HIKURANGI MARGIN
SINCE THE LAST GLACIAL MAXIMUM**

H. Poudroux^{1,2}, J.N. Proust¹, G. Lamarche², A. Orpin²

¹Géosciences, CNRS & Université de Rennes1, 35042 Rennes cedex, France.

²National Institute of Water and Atmosphere (NIWA), Wellington 6241, NZ.
hugo.poudroux@univ-rennes1.fr

New evidence from the deep Raukumara sedimentary margin shows numerous mass transport deposits of varying thickness, character and inferred activity since the LGM. We focus on three different sedimentary slope basins: the Matakaoa Turbidite System (MTS), the Poverty mid-slope basins and the Ruatoria basin which feed the deep turbidite-filled Hikurangi Trough at the convergent Pacific-Australia Plate Boundary.

A complete sedimentary record is captured by four Calypso giant piston cores (<20m) collected during the Marion Dufresne MATA CORE Project and a number of shorter piston cores from 1000–3500 m depth. Tephrochronology and radiocarbon dating on mixed planktonic foraminifers provide excellent age control since 18 ka. Lithofacies are characterised using visual description, X-Radiograph, grain size, gamma density and magnetic susceptibility, which collectively yield the following depositional modes: (1) hemipelagites; (2) volcanic airfall; (3) proximal debrites; (4) hyperpycnites; and (5) turbidites. Turbidites, with a thickness ranging from 1 to 75 cm, are the most common gravity-driven deposits and are often stacked, indicating deposition from multiple flows either simultaneously or in rapid succession. Based on grain size and internal structures, five low-density turbidites are identified: muddy, silt laminae, silty, sandy and basal reverse grading turbidites; the latter are rare. Contemporaneous to volcanic eruption, primary monomagmatic turbidites constitute a particular facies with a majority of volcanic grains from a single eruption.

Turbidite frequency and sedimentation rate vary strongly since the LGM. The MTS is essentially active during low stand and the beginning of the marine transgression at ~17 ka. The Ruatoria and Poverty systems remain active today, but turbidite frequency (9.6 turbidites/ka) and sedimentation rate (285 cm/ka) sharply increased during the low stand period. Holocene high stand frequency ranges from 1.4–3.6 turbidites/ka and the range of sedimentation rate in deep basins (1500–3000 m) is 60–110 cm/ka.

RECENT CHALLENGES IN GEOTHERMAL PIPING DESIGN AND CONSTRUCTION

S. Prasad¹ & B. Knyvett²

¹Development Department, MB Century, PO Box 341, Taupo 3351

²Development Department, MB Century, PO Box 341, Taupo 3351
bknyvett@mbcentury.com

This paper covers some recent challenges in geothermal cross country piping design and construction. Two cases of complicated large pipe spans are discussed, where the pipe is required to support itself to a greater extent than with a normal cross country pipeline design. In these cases the shape of the pipe becomes part of the support structure. Simplification of tall support structures is considered, with a comparison to an alternative design, and emphasis on the importance of piping engineers being involved in structural support design. The challenges associated with designing a pipeline to be supported on a flexible bridge are covered. Finally the design of a pipeline on a steep slope will be examined, including modifications to existing foundation design methods. The solutions consider environmental, economic, construction, and time constraints, on top of the mechanical and structural engineering requirements.

EXTENDING THE LATE HOLOCENE DINOFLAGELLATE CYST REFERENCE DATABASE FOR THE NEW ZEALAND REGION

J.Prebble¹, E.Crouch², L.Carter¹ & G.Cortese²

¹Antarctic Research Centre, Victoria University of Wellington

²GNS Science, Avalon, Lower Hutt.
Joe.prebble@gmail.com

Since development of the first transfer functions in the 1970s, the use of faunal environmental proxies (including dinoflagellate cysts) to derive qualitative environmental parameters has become well established. The use of faunal assemblages as a quantitative paleo-environmental proxy requires a high quality, internally consistent, database of modern distribution. The geographical distribution of dinocysts in modern sea floor sediments is reasonably well documented for a number of ocean basins, but is noticeably sparse to the west and north of New Zealand.

We present analysis of dinoflagellate cyst concentrations in 120 new sea floor sediment samples from around New Zealand and the Tasman Sea, which adds to the published Southern Hemisphere modern database of >400 sites. Distribution of the assemblages are explored by multivariate analysis against sea surface temperature, nutrient concentrations, salinity, and satellite derived productivity data.

Marked assemblage changes are observed across the Subtropical Front. Subantarctic waters are dominated by *Nematosphaeropsis labyrinthus*, *Dalella chathamensis* and *Impagidinium pallidum*, while cysts characteristic of Subtropical waters include *Impagidinium aculeatum* and *Spiniferities ramosus*. *Selenopemphix quanta* other Peridinioid cysts are more abundant in areas of higher productivity.

C-14 ages were obtained from single foraminifera picked from 48 of the samples. Over 95% of the samples containing dinoflagellate cysts returned a C-14 age of less than 7ka.

METHODS OF IDENTIFYING MĀTAURANGA MĀORI FOR IWI/HAPŪ PLANNING AND VOLCANIC HAZARDS MONITORING APPROACHES

J.N. Procter¹, S.J. Cronin¹, G. Harmsworth²

¹ INR, Massey University, Private Bag 11 222, Palmerston North, New Zealand.

² Landcare Research, Private Bag 11052, Palmerston North, New Zealand.

J.N.Procter@massey.ac.nz

There is an urgent need to articulate and document mātauranga Māori (Māori knowledge) and use this knowledge to complement western science. The wealth of mātauranga needs to be recognised and promoted. While a certain amount of ethnological information exists, there is a paucity of mātauranga Māori and it is seldom used in a complementary way alongside western science to better understand the environments we live in. In parallel to this lack of incorporation and understanding by western science of Māori links to the environment and views of natural hazards, Māori/Iwi do not have the appropriate tools to articulate their cultural values in a way that will ensure inclusion. Systems, processes and tools are urgently required to record, store and translate Māori knowledge into useable forms for future generations. Accurate and reliable knowledge and information of volcanic cultural landscapes can be used to more effectively plan, monitor and manage risk, and adapt to changing situations, while increasing the social capital of the Iwi. There is increasing need to include different perspectives into monitoring programmes that are understood, driven and accessed by communities as well as researchers, planners and policy makers.

GEOLOGICAL MAP OF NEW ZEALAND: A NATIONALLY SIGNIFICANT DATABASE

M.S. Rattenbury

GNS Science, PO Box 30368, Lower Hutt.

m.rattenbury@gns.cri.nz

The Geological Map of New Zealand (GMNZ) supports the Nationally Significant Database responsible for archiving geological maps and the construction of new geological maps of New Zealand and our territories. GMNZ manages a collection of geological maps dating back as far as the 1800s ranging from published geological maps through to unpublished field sheets containing information unavailable anywhere else. Dominating recent activity within GMNZ has been the long-running QMAP 1:250 000 Geological Map of New Zealand project. QMAP as originally envisaged back in 1994 is soon to complete the last of the 21 geological maps and explanatory texts that describe the geology of New Zealand. The maps have been produced direct from GIS software to high cartographic standards. The GIS platform has also enabled the release of equivalent map data in digital form as raster images and vector GIS format files. Through GMNZ the QMAP project is moving into an episodic update and maintenance phase through the building of a seamless QMAP GIS that will become the most up-to-date national geological map dataset. Other GMNZ projects include the geological map of South Victoria Land, a new 1:1 million Geological Map of New Zealand, and a geological map of Tongariro National Park. Two substantial projects at the planning stage are centred on detailed geological mapping of urban and resource areas. Cities and areas where significant mineral, hydrocarbon, groundwater and/or geothermal potential are known or inferred will be targeted with new geological mapping and data assembly. The concept of a geological map is being extended with 3D modelling software and visualisation tools to better communicate our understanding of New Zealand's geological framework.

A DIGITAL DENSITY MODEL OF NEW ZEALAND FROM LINKING THE QMAP AND PETLAB DATABASES

M.S. Rattenbury¹, N. Mortimer², R. Tenzer³, P. Sirguey³, J. Nicolson³

¹GNS Science, PO Box 30368, Lower Hutt.

²GNS Science, Private Bag 1930, Dunedin.

³School of Surveying, University of Otago, PO Box 56, Dunedin.
m.rattenbury@gns.cri.nz

The conclusion of the long-running QMAP 1:250,000 Geological Map of New Zealand project is opening new opportunities for summary research applied to the whole of New Zealand. This is expedited through the rich attributes that describe the geological features in the QMAP GIS database that enable links to other datasets. The QMAP GIS database has been combined with the PETLAB geo-analytical database to create a derivative digital density model of onshore New Zealand. By linking main rock types identified from more than 1800 mapping units in the QMAP dataset with 56 equivalent rock types identified in the PETLAB dataset, mean measured wet densities from PETLAB have been associated with areal extents from QMAP mapping units covering more than 85% of the land surface. A further 67 main rock types from QMAP not present in the PETLAB dataset were assigned densities derived from the published literature.

The surface geological composition of New Zealand is dominated by metamorphosed sedimentary rock (31%, mostly Mesozoic greywacke), unmetamorphosed sandstone and mudstone (19%), and unconsolidated sediment and pyroclastic volcanic detritus (28%). This includes 21% greywacke (mean 2639 kg/m³, 469 samples) and 21% gravels (mean 2309 kg/m³, 9 samples). A mean surface rock density of 2440 kg/m³ for New Zealand has been calculated. The North Island mean of 2336 kg/m³ reflects the predominance of relatively young, weakly consolidated sedimentary rock, tephra and ignimbrite, compared to the South Island's 2514 kg/m³ mean where igneous intrusions and metamorphosed sedimentary rock, including schist and gneiss, are more common. All of these values are significantly lower than the mean density of the upper continental crust that is commonly adopted in geological, geophysical, and geodetic applications (2670 kg/m³), typically assumed to be igneous rock. The lighter density has implications for the calculation of the geoid surface and gravimetric reductions through New Zealand.

EARTHQUAKE DETECTION AND LOCATION VIA WAVEFORM CROSS-CORRELATION IN THE ROTOKAWA GEOTHERMAL FIELD

Zara Rawlinson¹, John Townend¹, Stephen Bannister²

¹SGEES, Victoria University of Wellington, PO Box 600, Wellington 6140

²GNS Science, PO Box 30-368, Lower Hutt 5040

raw.zara.son@gmail.com

The aim of this project is to characterise microseismicity associated with injection in the actively exploited Rotokawa Geothermal Field by detecting and locating small earthquakes using waveform-matching techniques. In recent years, advances in data storage and computing power have seen continuous microseismic monitoring become a routine component of geothermal reservoir imaging. Microseismicity in geothermal fields is commonly associated with temperature and pressure changes in the reservoir, usually in close association with injection. Accurately locating this microseismicity can elucidate permeability pathways and structural features, and thereby provide additional insight into the reservoir's structure and behaviour.

Accurate detection and location of microearthquakes in geothermal fields is often complicated by the low signal to noise ratio (SNR) of most events of interest. A number of factors serve to reduce SNR in geothermal environments, including surface noise sources such as power plants, strong attenuation associated with high temperatures, and the low magnitudes of typical geothermal seismicity. However, the confined geometry of geothermal fields provides a limited set of sources and propagation paths affecting seismic waveforms. Accordingly, high-SNR events ("master events") identified manually can be used to detect lower-magnitude earthquakes with similar locations and focal mechanisms via waveform-matching.

In this study, waveform templates of master events identified during routine analysis of Rotokawa seismicity by GNS Science are cross-correlated with continuous seismic data, and signal detectability is enhanced by stacking correlation coefficients from single sensors across the Rotokawa network to create a network correlation coefficient. Software has been developed to perform low-magnitude earthquake detection using this matched filter technique, and preliminary results indicate an improvement in our ability to systematically detect earthquakes as small as $M_L \sim 0$.

This collaborative study has been made possible with data and funding provided by Mighty River Power, which manages the Rotokawa Geothermal Field. That support and ongoing discussions are gratefully acknowledged.

THE USE OF ISOTOPE AND CHEMICAL WATER CHARACTERISATION IN UNDERSTANDING SEEPAGE PATHWAYS AT TWO WAIKATO RIVER DAMS

S.A.L. Read¹, J. Howes², U. Morgenstern¹ & N. Connell³

¹GNS Science, PO Box 30368, Lower Hutt.

²Mighty River Power Ltd, PO Box 445, Hamilton.

³DamWatch Services Ltd, PO Box 1549, Wellington.

s.read@gns.cri.nz

Water chemistry, water dating, stable isotope signatures and temperature measurements provide up-to-date techniques to identify the origins and pathways of seepage flows under and around dams. This is based on their use at Arapuni and Aratiatia Dams on the Waikato River, New Zealand.

Water samples were taken from drillholes and flow monitoring weirs located at strategic locations in the dam vicinities plus from the reservoir, as well as temperatures being measured at sampling points and profiled in boreholes. At both sites separate sources of seepage water were differentiated using signatures from chemistry (major anions and cations) based on hierarchical cluster analysis, age (Tritium and chlorofluorocarbon dating) and mixing ratios, stable isotopes (oxygen and deuterium) and the precise (<0.05°C) temperatures. At Arapuni the separation of local groundwater and lakewater sources helped define individual seepage paths in the ignimbrite dam foundations, while at Aratiatia the pathway through a groundwater barrier across a rhyolite dome was illustrated to be more indirect than immediately beside power station structures. A key to the success of the water characterisation programmes at both sites was the use multi-parameter approaches as no single technique provided a definitive answer.

WORKING TOWARDS SUSTAINABLE, ZERO-EMISSION GEOTHERMAL CITIES

K. Regenauer-Lieb^{1,2} & Western Australian Geothermal Centre Team^{1,2,3}

¹University of Western Australia, M004, 35 Stirling Av., 6009 Crawley, Australia

Klaus@cylene.uwa.edu.au

²CSIRO Earth Science & Resources Engineering, ARRC, 26 Dick Perry Avenue, Kensington, Australia

³Curtin University, GPO Box U1987 Perth, Australia

Many major cities are built on naturally hot aquifer systems at relatively shallow depth. High permeabilities in such hot sedimentary aquifers make them an ideal target for geothermal energy extraction. The Western Australian Geothermal Centre of Excellence was funded in 2009 by the WA State Government with the mission to develop new methods to explore for and utilise such low-grade heat, an overlooked opportunity for broadening the footprint of geothermal energy utilization in the world. The Centre is particularly focusing on the geological settings where exploitable heat is available right where it can be used. We will present the first applications of our novel exploration and utilization methods, which do not only provide design templates to power sustainable, zero-emission geothermal cities but provide solutions for energy and water supply problems in areas without infrastructure such as remote mine sites and communities.

One such example project is the geothermal cooling project of the Pawsey Supercomputer/ARRC building. The Australian Government has funded the Pawsey supercomputer in Perth, providing computational infrastructure intended to support the future operations of the Australian/NZ Square Kilometre Array (SKA). Cooling the Pawsey supercomputer may be achieved by direct geothermal heat exchange (heat abstraction to power a chemically driven sorption chiller and heat rejection into the shallow aquifer) rather than by conventional electrical power cooling, thus significantly reducing the carbon footprint of the Pawsey Centre and demonstrating an innovative green technology that is widely applicable in industry and urban centres across the world. In collaboration with the Australian National Centre of Excellence for Desalination we also intend to use the extracted geothermal water both as a heat source and feedstock to develop our protected distillation based desalination technology by constructing a containerized 4 m³/day desalination plant. The exploration well is scheduled to be completed in 2011. Establishing the Pawsey Centre/ARRC as a geothermal demonstration site will confirm the long-held potential of the Perth Basin as a significant direct heat renewable energy source. If successful, the Pawsey Centre/ARRC deployment will provide proof-of-concept for much larger-scale exploitation of the Perth Basin hot, sedimentary aquifers. We here invite collaborations for an open hole laboratory used by the R&D community and geothermal industry. Our aim is to use knowledge gained from this laboratory to help in other projects where the scope of geothermal industry will be understood and integrated as a firm building block into a sustainable future.

DO MACROALGAL ENVIRONMENTS LEAVE A GEOLOGICAL SIGNATURE? MODERN TEST CASE FROM KAIKOURA, NEW ZEALAND.

C.M. Reid¹, N.P. James² & Y. Bone³

¹ Dept of Geological Sciences, Univ. Canterbury, Private Bag 4800, Christchurch

² Dept of Geological Sci. & Geological Eng., Queen's Univ., Kingston, Ontario, Canada

³ School of Earth and Environmental Sciences, Univ. of Adelaide, SA 5005, Australia.
catherine.reid@canterbury.ac.nz

Brown, red and green macroalgae in modern temperate marine environments are ecosystem-forming primary producers on rocky substrates, yet they have a poor preservation potential and few fossil examples are known from the rock record. Macroalgal forests, as carbonate producers, are largely unrecognised within the cool-water carbonate realm even though they host a wide variety of calcareous organisms with good preservational potential. Some species of molluscs, sea urchins and crustaceans only live within the understorey of macroalgal forests. These, and other, calcareous flora and fauna are the key to identification of macroalgal environments in the rock record.

Modern macroalgal forests at Kaikoura, New Zealand, exhibit a clear zonation of calcareous components controlled by substrate topography, wave exposure, water depth and light penetration. The prominent live calcareous components include encrusting and foliose coralline red algae, molluscs, bryozoans, echinoderms, calcareous worms, ascidians and crustaceans, as well as sponges and other soft bodied invertebrates. The sediments accumulated beneath and adjacent to the algae at Kaikoura are bioclastic, terrigenous sands and gravels; with bioclasts of coralline algal fragments and rhodoliths, barnacles, molluscs, spirorbids and bryozoans. Although the shallow, wave exposed settings that promote growth of macroalgal forests are limited in areal extent, their contribution via skeletal carbonate may be considerable.

In the rock record, terrigenous sands and gravels rich in coralline, barnacle, mollusc, and bryozoan fragments, that occur in association with hard-substrate unconformities in a cool-water realm, must be considered as representatives of past macroalgal environments.

SUB-SURFACE EXPRESSION OF SAND VOLCANOES IN THE AVON-HEATHCOTE ESTUARY INDUCED BY THE DARFIELD EARTHQUAKE; ANALOG FOR SEDIMENTARY STRUCTURES IN THE ROCK RECORD

C.M. Reid¹, J.Q. McCombe², N.K. Thompson¹, T.E. Laird¹ & J.R.M. Irvine¹

¹ Dept of Geological Sciences, Univ. Canterbury, Private Bag 4800, Christchurch

² 148B Rockinghorse Road, Southshore, Christchurch

Among the deformation features produced in Christchurch by the September 4th Darfield Earthquake were numerous and widespread "sand volcanoes". Most of these structures occurred in urban settings and "erupted" through a hardened surface of concrete or tarseal, or soil. Sand volcanoes were also widespread in the Avon-Heathcote Estuary and offered an excellent opportunity to readily examine shallow subsurface profiles and as such the potential appearance of such structures in the rock record.

At the time of the earthquake the estuary was near to low-tide and the extensive tidal flats were sub-aerially exposed. Several hundred sand volcanoes formed across the tidal flats on the eastern side of the Avon-Heathcote Estuary. Local residents reported a strong sulphurous smell immediately after the earthquake; the result of erupted anoxic, H₂S rich sands. At the surface, volcano diameter ranged between approximately 20-200cm, with most cones 50-100cm in size. Many were elongate or aligned in a more or less N-S direction and all cones showed a circular or elongate central crater.

Sub-surface features of these sand volcanoes were examined a few days after the earthquake following several tidal cycles. Most surface features had been removed, but subtle topography confirmed vent locations. Cross-sections revealed short subsurface conduits of approximately 25cm diameter and all cases the erupted sediment was fine grey sand. The source depth of the erupted material varied between 10cm and >30cm. The example sourced from 10cm depth also displayed subtle down-warping of overlying sediments in the vent area. In this sand-rich estuarine environment the conduit structures were only visible if they cross-cut black organic-rich sands, bioturbated muds and sands, or shell layers. Many of the conduits were still water saturated and collapsed easily.

The feature most likely to be preserved in the geological record is the thick conduit cross cutting other structures, with or without a thin trace of erupted sediments. Further de-watering of the sands within conduits and source sediments may occur with subsequent overburden, but these could not be seen in fresh, still wet, exposures.

VARIATION IN VEIN CHARACTERISTICS AND TEXTURES IN METABASIC AND QUARTZOFELDSPATHIC ALPINE FAULT MYLONITES

Z. Reid Lindroos¹, V. Toy¹ and R. Norris¹

¹Dept of Geology, University of Otago, PO Box 56, Dunedin
zoe.reidlindroos@gmail.com

Crystallographic Preferred Orientations (CPO) in ~20 quartz vein samples from a fault perpendicular section within the hanging-wall mylonites of the Alpine Fault were investigated using Computer Integrated Polarisation Microscopy (CIP). The quartz veins occur within two different mylonitic lithologies; quartzofeldspathic mylonite and metabasic mylonite. The quartz veins mostly lie at low angle to or parallel to the mylonitic foliation. These veins may initially have formed in three different scenarios, each of which should produce a different final CPO; (1) veins inherited from the Alpine Schists which were already deformed before incorporation into the mylonite zone, (2) veins opened parallel to foliation at depth within the mylonite zone, and (3) veins opened at high angle to foliation at depth within the mylonite zone. In all three scenarios we expect an original CPO within the veins.

The samples display CPOs ranging from crossed girdles, representative of low temperature basal <a> glide to concentrated Y-maxima fabrics characteristic of prism <a> glide, and possible constrictional fabrics. CPOs within quartzofeldspathic and metabasic mylonites differ significantly. The metabasic mylonites have more grains favorably oriented for prism<a> glide, and some indicate antithetic sense of shear to adjacent quartzofeldspathic mylonites, and to the overall sense of shear within the Alpine Fault zone. The large variation in CPO between veins hosted in quartzofeldspathic and metabasic lithologies suggests the rheologically distinct metabasic pods may either shield quartz veins from deformation, or focus deformation into them.

Several veins within both lithologies have a domainal CPO, which may indicate that they have not undergone enough recrystallisation to completely change the initial CPO, or that different starting orientations responded differently to the same deformation. In either case, preservation of these domains suggests these veins were generated within the mylonite zone rather than inherited from the Alpine Schist.

HOW AUSTRALIA LOST NEW ZEALAND?

P. F. Rey & D. R. Müller

Earthbyte group, School of Geosciences, The University of Sydney, Sydney NSW 2006
patrice.rey@sydney.edu.au

Collapse of Cordilleran orogen, marginal basin opening and detachment of micro-continents from continental mainlands is often described as the consequence of slab rollback. Along the East Gondwana margin, the coincidence between change in plate motion and the switch from contractional to extensional tectonics suggests that slab rollback was not the driving mechanism behind the Late Cretaceous tectonic switch.

Plate reconstruction in a mantle reference frame show that from 140 to 105 Ma Gondwana moved Eastward toward the Pacific Plate. This convergence was largely accommodated by the subduction of the Pacific plate under Gondwana. From 105 to 95 Ma, Gondwana remained stationary. Subsequently, Australia started moving away from Antarctic in a northwesterly direction, resulting in oblique opening of the early Southeast Indian Ocean. This path suggests that, at around 100 Ma, the basal traction that produced and sustained the East Gondwana Cordillera decreased significantly allowing for oceanward gravitational collapse. The oceanward spreading of the continental crust continued until the opening of the Tasman sea from about 90 to 52 Ma, resulting in the formation of continental ribbons.

On the basis of 2D thermo-mechanical numerical experiments and the Late Cretaceous evolution of the east Gondwana margin we propose a new model for the formation of marginal basin and that of continental ribbons. We argue that, upon a decrease in the basal traction imposed on the overriding plate by the subducting slab, the buoyant rise of the mantle wedge drives a range of processes including: gravitational collapse of Cordilleran orogens, the formation of marginal basins, sea floor spreading, slab rollback and the formation of continental ribbons.

LOW-ENTHALPY GEOTHERMAL SOURCES IN NEW ZEALAND AND SUBSURFACE TEMPERATURES

A. G. Reyes

GNS-Science, 1 Fairway Drive, Avalon, Lower Hutt
a.reyes@gns.cri.nz

Geothermal energy is available throughout New Zealand albeit not always easily accessible or economically viable using present technology. Heat can be derived from thermal spring systems or hot dry rock. At shallow depths heat from rock can be harnessed using ground source heat pumps. Higher temperatures in low-enthalpy regions can be accessed by deep abandoned oil, gas and water wells, abandoned mine shafts in mineral and coal regions and new wells drilled in high heat flow regions (Reyes, 2007).

The best known geothermal systems in the country are located in the Taupo Volcanic Zone (TVZ) and in Ngawha where subsurface temperatures are >250°C and geothermal energy is harnessed mainly for power. In contrast to the TVZ, low-enthalpy spring systems are widely distributed in 17 different tectono-geographic regions in the North and South Islands and thus, accessible to numerous communities in the country for direct heat use and, in a few areas, for possible low-scale binary power production. Hot spring discharges in low-enthalpy systems have temperatures up to 85°C in the North Island and up to 66°C in the South Island. Based on alkali cation geothermometry, the highest subsurface temperatures occur in the Coromandel region including Great Barrier Island (200-250°C), Auckland, Bay of Plenty, western Waikato and Hauraki Rift Zone (150-220°C) in the North Island. In the South Island the highest estimated subsurface temperatures occur along the North Alpine Fault System (200-250°C). Estimated surface thermal energy in the North Island low-enthalpy systems is about 33 MWt compared to only 1.5 MWt in the South island. This is <2% of the total surface heat output in the Taupo Volcanic Zone (2700 MWt) which comprises <3% of the area of onshore New Zealand.

CHANGES IN THERMAL WATERS OF THE SOUTH ISLAND AFTER THE DARFIELD EARTHQUAKE

A. G. Reyes¹, J. Cole-Baker², B. W. Christenson³ & S. Cox⁴

¹GNS-Science, 1 Fairway Drive, Avalon, Lower Hutt

²Wairakei Research Centre, 114 Karetoto Road, Wairakei, Taupo

³National Isotope Centre, 30 Gracefield Road, Lower Hutt

⁴Dunedin Research Centre, 764 Cumberland Street, Dunedin
a.reyes@gns.cri.nz

More than 30 thermal springs in the South Island have been surveyed in the last few years (Reyes et al, 2010), providing a useful baseline data that may be used to assess and monitor the effects of the 7.1 magnitude Darfield earthquake on the movement of cold meteoric waters and thermal solutions, upflow of deep crustal fluids, changes in relative crustal permeability and variations in water-rock interaction. Within 4-9 days after the earthquake, five thermal spring systems along the Alpine Fault (Copland, Fox, Maruia, Sylvia Flats, Hanmer) and three in Christchurch (Cass Bay, Rapaki Bay, Motukarara) were resurveyed and fluid samples for chemical and isotopic analysis collected where possible. In general, the flow rates of thermal springs in the Alpine Fault Zone and in Christchurch increased by 6x to 10x in September 2010, relative to measurements in 2003 and 2005. Discharge temperatures in the springs in Fox, Copland, Sylvia Flats and Rapaki and wells in Maruia and Hanmer have remained virtually unchanged. Similarly, the silica, K/Mg and K/Na temperatures after the earthquake are within the error limits of the geothermometers, except for Cass Bay (apparent increase in subsurface temperatures) and Sylvia Flats (apparent decrease). Some of the springs are producing more gas than previous years, e.g. Rapaki Bay and Fox. In Sylvia Flats discoloured turbid springs, warmer than the river waters by about 2°C, have appeared. In general, the chemical compositions of the thermal waters show little change from previous surveys except for the effects of dilution by surface meteoric waters. The dilution may be due to shallow incursion of groundwater in response to the shaking as a result of localised compaction of pore space and possibly increased permeability of structures. Contamination of spring waters by rainfall and changes in the river levels may also contribute to dilution trends. However, because of slow rates of reaction, any changes in subsurface temperatures or any influx of deep crustal fluids due to the earthquake may only be discernible after more time has elapsed.

HYDROTHERMAL MINERAL REPOSITORIES OF B, LI AND CL

A. G. Reyes¹ & W. J. Trompeter²

¹GNS-Science, 1 Fairway Drive, Avalon, Lower Hutt

²National Isotope Centre, 30 Gracefield Road, Lower Hutt

a.reyes@gns.cri.nz

Of the three elements, Cl is the most conservative of the trace elements, Li the least and B midway between the two. At the onset of alteration of rhyolite and andesite, where alteration intensity is <85%, Cl is reduced by nearly 60% and B and Li are also depleted, albeit less. With increasing alteration intensity, Cl is further depleted, up to >99% of the original rock composition, B and Li are either augmented or depleted, depending on the presence of repository secondary minerals. In low rank alteration assemblages formed at temperatures <200°C, B is preferentially uptaken by kaolinite, smectite and interlayered illite-smectite. In some samples enriched in B, H₂O⁺ is also high suggesting that B may occur in smectite interlayers. At >200°C, B enters into the chlorite structure. The highest concentrations of Li were measured in pumpellyite, chlorite, smectite, quartz and wairakite. However because of their abundance in altered rocks, the main repositories for Li are chlorite, quartz, smectite and illite in highly illitized samples. In general the Li content of quartz and illite increases with temperature but decreases in chlorite. Boron concentrations in chlorite and quartz generally increase with temperature. However B concentrations increase in illite up to 200°C then decrease.

THE SEISMOTECTONIC CONTEXT OF THE 2010 DARFIELD EARTHQUAKE

Martin Reyners¹, John Ristau¹, Hugh Cowan² & Jarg Pettinga³

¹GNS Science, P.O. Box 30368, Lower Hutt.

²Earthquake Commission, P.O. Box 790, Wellington.

³Dept. of Geological Sciences, University of Canterbury, Private Bag 4800, Christchurch.

m.reyners@gns.cri.nz

We have good control on crustal structure in the region of the Darfield earthquake from a dense deployment of portable seismographs undertaken in 1990. Arrival time data from both earthquakes and shots recorded in that experiment have been incorporated into the New Zealand-wide 3-D seismic velocity model. We use this model to relocate 10 years of seismicity prior to the 2010 Darfield earthquake, and thus determine the seismotectonic context of the sequence. Prior seismicity is concentrated in two structures: the NW-dipping subducted Hikurangi Plateau (~10-50 km depth), and the décollement beneath the range front (~10 km depth) where Chatham Rise greywacke and schist capping the plateau are being subducted. We also relocate the Darfield mainshock and first 30 hours of M_L ≥ 4.0 aftershocks using the same 3-D seismic velocity model. The mainshock hypocentre is located 3 km north of the central part of the Greendale fault surface trace, at 10.8 ± 0.3 km depth (close to the Cretaceous plate interface between the Hikurangi Plateau and overlying schist). Both first motion data and a regional centroid moment tensor inversion demonstrate that the earthquake started as a pure thrust normal to the current plate boundary. Teleseismic and local data indicate that this initial thrust subevent had less moment than the subsequent strike-slip subevent. Yet the radiated seismic energy from the thrust subevent appears to have been much larger than that from the strike-slip subevent. The thrust subevent may have provided the required basal boundary condition for rupture of the overlying strike-slip Greendale fault. We are currently working to refine the dimensions of the various subevents involved in the earthquake, by relocating later aftershocks recorded by GeoNet and 13 portable seismographs installed immediately after the mainshock.

HOT SEDIMENTARY AQUIFER GEOTHERMAL ENGINEERING FRAMEWORKS IN THE PERTH METROPOLITAN AREA

L.P. Ricard^{1,2} & M. Pujol³

¹WA Geothermal Centre of Excellence, ARRC, PO Box 1130, Perth, Australia

²CSIRO Earth Science and Resources Engineering, PO Box 1130, Perth, Australia

³Rockwater Pty Ltd, Jolimont, WA 6014, Australia

Ludovic.Ricard@csiro.au

Currently, six direct-use geothermal projects have been completed and are operating in the Perth Metropolitan Area. These projects involve production from and injection to shallow (<1000 m depth) confined aquifers for applications including swimming pool heating and providing heat for thermal regulation. Since the first project in the Perth Metropolitan Area in 1998, various geothermal reservoir engineering methods have been introduced and evaluated. The general framework is now getting well established for depths up to 1,000 m. As a consequence, shallow Hot Sedimentary Aquifer (HSA) applications are now booming. However, deeper resources have not yet been explored and more challenges lies ahead. Reservoir engineering studies for HSA geothermal production place particular emphasis on data collection, interpretation and modelling. As for other types of geothermal plays, temperature, reservoir volume and pressure are key factors for HSA systems. In addition, injection pressure, pumping water level and achievable flow-rates are key parameters in the economics of direct-use projects targeting HSA systems. Thermal characterization is performed using hydrogeological knowledge and field investigations such as wireline log and results in the identification of conductive and advective regimes within the lithological column. The pumping water level and injection pressure versus achievable flow rate are assessed during well tests. The reservoir volume is investigated using the hydrogeological knowledge of the area together with well test analysis. Additionally, reservoir geochemistry and well clogging processes must also be considered as they have the potential to dramatically increase pumping costs for and even reduce sustainability of water re-injection. The long term objective of the Industry is to target warmer temperature and greater flow rates. With project scale-up comes more challenges, including pressure and temperature losses, well and pump designs, field implementation logistics, and so on. In this talk, we present a reservoir engineering case study of a direct-use HSA project in the Perth Metropolitan Area and then discuss possible extension of the shallow framework to greater depths in HSA systems.

RECONSTRUCTING THE HOLOCENE ALLUVIAL RECORD OF NORTHLAND, NEW ZEALAND

J.M. Richardson¹, I.C. Fuller¹, K.A. Holt¹, N.J. Litchfield² & M.G. Macklin³

¹Geography Programme, School of People, Environment and Planning, Massey University, Private Bag 11 222, Palmerston North

²GNS Science, PO Box 30368, Lower Hutt

³Institute of Geography & Earth Sciences, Aberystwyth University, SY23 3DB, UK

j.m.richardson1@massey.ac.nz

Fluvial sedimentary sequences preserve a record of river development and have been used to investigate the relationship between environmental change and river behaviour. Reconstruction of Holocene alluvial histories can identify episodes of increased fluvial activity which can be compared with independent palaeoclimate proxy records. The data can be used to assess the synchrony of different regional responses to changes in climate, and improve the forecasting of the impacts of predicted hydro-climate change on fluvial systems.

This paper presents the first results from a project aimed at reconstructing Holocene fluvial activity in Northland rivers. Since Northland is located relatively remotely from volcanic and tectonic factors that disturb river catchments, these are the most likely of any New Zealand rivers to be directly driven by climate change. In this study, the first of its kind in New Zealand, interpretative valley floor mapping, sedimentology and ¹⁴C- dating has been used to reconstruct the alluvial history of eight sites in the Northland region. Palaeoflood depositional units were identified and ¹⁴C-dated at six floodplain sites. At two palaeochannel locations sedimentary discontinuities provided dates for the onset of increased fluvial activity. Floodplain sedimentation rates suggest an acceleration of valley floor infilling after 1000 cal. BP.

This preliminary work has confirmed the potential of this research in elucidating a model of Holocene river development in Northland. The focus for the next stage of the project will be targeted field research aimed at increasing the temporal resolution of the Holocene alluvial record in the Northland region.

ACOUSTIC IMAGING IN GEOTHERMAL WELLBORES

M. Rickman

Tiger Energy Services NZ, Taupo, New Zealand

Presentation detailing the application of Tiger's Acoustic Formation Imaging Tool (AFIT) in the New Zealand Geothermal Industry.

Covered topics will be:

- Overview of how the tool works
- Logged images from NZ Wells
- Application of the tool in Australia
- Casing inspection application
- Overview of Tiger's High Temperature Measurements suite

THE USE OF REMOTELY SENSED GEOSPATIAL DATA IN RESPONSE AND RECOVERY FROM THE DARFIELD EARTHQUAKE

W. Ries¹, I. Campion², R. Elley² & T. Farrier³

¹GNS Science, PO Box 30368, Lower Hutt 5040, New Zealand

²Environment Canterbury, PO Box 345, Christchurch 8140, New Zealand

³NZ Aerial Mapping, PO Box 6, Hastings 4122, New Zealand

w.ries@gns.cri.nz

Following the Darfield Earthquake a large amount of high resolution remotely sensed geospatial data (satellite imagery, LiDAR and aerial photography) was collected to assess ground deformation and damage to buildings and infrastructure. The amount of data is perhaps the largest collected in New Zealand for an event of this type. This combined with a wealth of remotely sensed geospatial data collected prior to the earthquake has, and will provide a valuable resource for the understanding of this and other similar events, ultimately informing research, recovery and future mitigation efforts.

We present a summary of the geospatial data that was collected focusing on use for immediate response, recovery and future research. A review of data collected of the surface rupture will be used to highlight issues with collecting and processing data in an emergency environment. From this overview we suggest strategies that could be useful for collecting these data for future earthquake events.

SLOPE FAILURE IN VOLCANIC MATERIALS AT THE TE TOTO AMPHITHEATRE, RAGLAN

C. Ritchie¹ & M.A. Brideau¹

¹Geology Programme, School of Environment, University of Auckland
crit007@aucklanduni.ac.nz

The Te Toto amphitheatre represents the geomorphic expression of an ancient slope failure on the north western slope of Mount Kairoi near Raglan, New Zealand. This study presents a geotechnical model of the materials observed at the site, and assesses potential mechanisms for the slope failure using kinematic and limit equilibrium analysis techniques.

Field estimates and laboratory index tests are used to geotechnically classify the materials present. Detailed rock descriptions following New Zealand Geotechnical Society guidelines are used in conjunction with rock mass quality estimates based on the Geological Strength Index (GSI). Preliminary results suggest that three geotechnical units are present at the site. A thick columnar jointed basalt is aerially extensive in the walls of the amphitheatre with a strong strength measurement and a GSI 55-60. Below the columnar basalt a pyroclastic flow deposit with an irregular contact was observed to be up to 8m thick. The pyroclastic material is composed of strong basaltic clasts in a weak sandy groundmass (GSI 35-40). A basal volcanic sediment layer with a distinctive orange colour is present throughout the amphitheatre with a maximum exposed thickness of 2m. This unit has a weak strength and a GSI of 40-45. The overall stratigraphic contact of the units is dipping seaward approximately 20°.

Stereographic kinematic analysis is used to assess the potential failure mechanisms. A slope gradient of 19° is assumed for average overall slope angle prior to the failure while a value of 55° is used for the wave cut cliff face. Five main discontinuity sets are identified in the rock mass. Kinematic analysis (assuming a 35° friction angle) suggests that failure by planar sliding is the most probable cause of failure on the average slope. The wave cut cliff face slope is also prone to toppling failure. Based on stereographic kinematic and limit equilibrium surface wedge analyses, sliding along a wedge intersection does not appear to be a dominant failure mechanism.

PALAEOMAGNETIC STATISTICAL CONCEPTS APPLIED IN REVERSE AS AN AID TO PRACTICAL NAVIGATION IN THE BUSH

D.J. Robertson

Physics Department, University of Auckland, Private Bag 92019, Auckland 1142.
d.robertson@auckland.ac.nz

This contribution explains the practical application of a concept set out in the Journal of Navigation (Vol 63, 2010, pp379-394) whereby some principles underlying the Fisher distribution used in palaeomagnetism and structural geology are adapted to facilitate rapid "dead reckoning" navigation as an aid to map reading. The basis of the technique is that if a journey is divided into N approximately straight segments of equal length L and bearings α_i then overall bearing is approximately the average bearing $\sum \alpha_i/N$ and the overall distance is approximately $R' = NL(1 - \text{var}(\alpha)/2)$, where α is measured in radians. The computation is straightforward, even under field conditions, with the help of a modern pocket calculator. Care must be taken to avoid unwanted multiples of 360° from infiltrating the calculation. The "error circle" is about 10% of R', provided that $\text{var}(\alpha)$ is less than 0.7 radians squared (i.e. the standard deviation in bearings is less than 48°). This is a useful aid to navigation in rugged, forested parts of New Zealand as a backup to GPS, which may lose lock or be otherwise unavailable.

OROCLINAL BENDING IN THE SOUTHERN NEW ENGLAND OROGEN, EASTERN AUSTRALIA

G. Rosenbaum

School of Earth Sciences, The University of Queensland, Brisbane, Australia.
g.rosenbaum@uq.edu.au

The New England Orogen, which formed during subduction and accretionary processes from the Devonian to Triassic, is the youngest and easternmost component of the Australian continent. The southern part of the orogenic belt, between Brisbane and Newcastle is characterised by a series of oroclinal structures. Structural information from the hinges of these oroclinal structures, complemented by new geochronological data, show that the geometry of the New England oroclinal structures is far more complex than previously suggested. It comprises of at least three, and possibly four, oroclinal structures that together delineating an ear-shape structure. The timing of oroclinal bending is restricted to a relatively short period during or after the emplacement of Early Permian (295-285 Ma) granitoids and prior to ~260 Ma, when voluminous I-type granitoids, crosscutting the oroclinal structures, have started to intrude. The development of this complex geometry must be taken into account in tectonic reconstructions of eastern Australia during the Early-Mid Permian. Possible models could involve complex interactions in a subduction zone from the type recognised in the Alpine-Mediterranean or eastern Indonesia, where formation of oroclinal structures are attributed to trench rollback, subduction segmentation and slab tear faults.

**THE WAITOA ANDESITE (KIWITAHU VOLCANIC GROUP):
A REDISCOVERED VOLCANO IN THE HAURAKI RIFT**

M. D. Rosenberg

GNS Science, Wairakei Research Centre, Private Bag 2000, Taupo.
m.rosenberg@gns.cri.nz

In the top left corner of Sheet 5 Rotorua 1:250k Geological Map of New Zealand (Healy, J., et al., 1964) is a very small area northeast of Morrinsville that is labelled as Miocene KIWITAHU Volcanics [*sic*] but is coloured yellow like the Pleistocene alluvium that surrounds it. During reconnaissance fieldwork for QMap 1:250k Rotorua, this apparently anomalous area was confirmed as low hills covered by boulders (and *in situ* rock) of porphyritic andesite lava, as first recorded on Sheet 5 by J. Schofield.

Previous geochemistry and dating studies of the KIWITAHU Volcanic Group (KVG) neither record the location of andesite, nor report any analyses of it. The purpose of this preliminary study is to announce a rediscovered volcano and to evaluate assumed geochemical affinities of the Waitoa andesite with KVG lavas. Geophysical studies of the Hauraki Rift (unpublished) recognised the andesite but could not identify surrounding coherent lava and interpreted the boulders as remnants of flows from volcanoes to the west.

New major and trace element geochemistry from whole rock XRF analysis of two fresh (0.3% LOI) lava samples overlaps with Coromandel andesite compositions, but is a closer match with published data for KVG lavas. Waitoa lava is medium-K andesite (61% SiO₂, 1.2% K₂O), unlike the nearest centres (e.g. Maungatapu, Ruru, Tahuna) which erupted mostly basaltic andesite (53-57% SiO₂). Instead, major element oxide abundances are most similar to northern KVG andesites, particularly at Waiheke Island. Similarly, incompatible trace element ratios plot with published data for northern centres. The Waitoa andesite has about 20% plagioclase and orthopyroxene phenocrysts/glomerocrysts. Hornblende, typically present in northern KVG lavas, is absent.

Further petrology and dating being undertaken will determine affinities between Waitoa and other KVG lavas and could test spatial patterns suggested by age and petrogenetic interpretation. Structural implications for the Hauraki Rift history are also being considered.

**NEITHER EFFUSIVE NOR EXPLOSIVE: ORIGINS OF PUMICE FRAGMENTS IN
SUBMARINE SILICIC VOLCANISM, KERMADEC ARC, SW PACIFIC**

M.D. Rotella¹, C.J.N. Wilson¹, R.J. Wysoczanski², S.J. Barker¹ & I.C. Wright³

¹SGEES, Victoria University of Wellington, PO Box 600, Wellington.

²National Institute of Water & Atmospheric Research, Private Bag 14901, Wellington.

³National Oceanography Centre, Southampton, United Kingdom.
mrotella@gmail.com

Pumice textures from subaerial explosive eruptions have been relatively well documented yet little is known about their submarine equivalents. The Kermadec Arc presents a unique opportunity to investigate the processes of submarine explosive volcanism, as it contains silicic volcanoes of similar age that have erupted chemically similar magmas at differing water depths. Here we present textural analysis data for clasts collected from subaerial deposits on Raoul volcano, as well as clasts from Macauley volcano (a large submarine caldera with a 3 km² subaerial exposure) dredged from the seafloor and collected from the subaerial exposure. Variations in vesicle texture, size and abundance in pyroclasts from these eruptives have been quantified using stereological image analysis techniques. Initial results show that pyroclasts from five eruptions of contrasting size from the subaerial Raoul volcano show little variation in bubble number density, with similar values to other published subaerial silicic volcanoes. Submarine erupted pyroclasts from Macauley volcano, however, show vast variations in textural characteristics. These pyroclasts display a strong gradient in vesicularity not observed in the subaerial realm, with vesicularity in a single clast ranging from 50 - 80 vol. % over less than 3-4 cm. Vesicle shapes range from strongly elongate at the pyroclast margins to rounded large vesicles within the pyroclast interior suggesting that they have experienced rapid quenching with ongoing degassing at their cores. The differences in the vesicle textures of pyroclasts from Macauley volcano submarine eruptives are attributed to differences in eruptive style, and the interaction of degassing magma with a large amount of water. Although pyroclast chemistry indicates that many samples from Macauley volcano were erupted in separate events of unknown size or style, these new observations support a model of eruption that is not entirely effusive or explosive but a hybrid style of eruption not previously recognised.

**THE USE OF MAGNETOTELLURIC AND TIME DOMAIN ELECTROMAGNETIC
METHODS IN THE GEOTHERMAL SURVEY OF MONTSERRAT, W.I.**

G.A. Ryan¹, S.A. Onacha¹, E. Shalev¹ & P.E. Malin¹

¹ Institute of Earth Science and Engineering, University of Auckland, Auckland.
g.ryan@auckland.ac.nz

Montserrat is a small island in the Lesser Antilles at the eastern end of the Caribbean Sea. Since 1995 there has been an actively erupting volcano on the island. The majority of the Lesser Antilles islands are volcanic due to the subduction of the Atlantic plate beneath the Caribbean plate. This region of the Caribbean is thought to have high geothermal potential. There have been geothermal surveys and studies in this region since the 1950s but there is currently only one operational geothermal power station in the Caribbean. This power station is located on the French island of Guadeloupe. In recent years there has been a renewed interest in exploiting the geothermal potential of this region. In this presentation, we discuss the results obtained from Magnetotelluric (MT) and Time domain electromagnetic (TDEM) techniques. Both techniques were used to help identify structures which may host geothermal resources on the island. The MT technique utilises naturally occurring magnetic and electric fields to measure the earth's impedance tensor at frequencies from 320 to 0.001 Hz. This data can then be inverted to produce variation in resistivity with depth among other things. TDEM is an active technique in which the inductive response of the earth to an artificially generated magnetic field is measured. In this survey the TDEM data were used to correct the static shift inherent in the MT data. Data from 28 MT soundings and 22 TDEM soundings were analysed and the results indicate the possible existence of a geothermal system controlled by NW and NE trending fault/fracture systems in the southwest of the island. Interpretation of the collected data indicates that a reservoir may exist at a depth of 800-1200m and could host fluids with temperatures in excess of 180 - 220°C.

RECENT NEW ZEALAND DEEP-WATER BENTHIC FORAMINIFERA – A NEW
MONOGRAPH

Ashwaq T. Sabaa¹, Bruce W Hayward¹, Hugh Grenfell¹, Helen Neil², Martin A.
Buzas³

¹Geomarine Research, 49 Swainston Rd, St Johns, Auckland

²NIWA, PO Box 14901, Kilbirnie, Wellington

³Smithsonian Institution, Washington DC, United States
a.sabaa@geomarine.org.nz

A new monograph on New Zealand's deep-water benthic foraminifera has just been published (2010) as a companion volume to an earlier monograph on New Zealand's shallow-water benthic foraminifera (Hayward et al. 1999). The new publication records 563 benthic foraminiferal species from deep water (>50 m) within the New Zealand Exclusive Economic Zone (EEZ). Three hundred and forty-seven of the most common or distinctive species are fully illustrated and their diagnostic features outlined. In combination with the shallow-water monograph, 504 New Zealand species are fully illustrated and described. Cluster and canonical correspondence analyses of census count data (59,000 specimens) are used to map the distribution of deep-water (50-5000 m depth) benthic foraminifera around New Zealand and relate this distribution to a number of environmental "drivers", such as quality, quantity and seasonality of organic carbon flux, sea-floor oxygen concentration, temperature, salinity, bottom current strength, and carbonate corrosiveness. A slightly greater proportion of deep-water (>100 m) species (69%) have a cosmopolitan distribution than do shallow water.

An improved guide to the use of foraminifera in assessing the paleoenvironments of Neogene fossil faunas is provided. Together these two monographs provide the modern analogue data that underpins the use of fossil foraminiferal faunas in New Zealand as proxies for studies on sea-level rise, earthquake displacements, human impacts on coastal environments, paleogeography, paleobathymetry, basin analysis, sequence stratigraphy, paleoproductivity, paleoceanography, ocean acidification, etc.

THE FOSSIL FAUNA OF MIOCENE HYDROCARBON SEEP
CARBONATES, NORTH ISLAND, NEW ZEALAND

K. P. Saether¹, K. A. Campbell & C. T. S. Little²

¹Geology, School of Environment, University of Auckland, Private Bag 92019,
Auckland

²School of Earth and Environment, University of Leeds, LS2 9JT, Leeds
k.saether@auckland.ac.nz

A diverse fossil fauna is described from 13 fossiliferous Miocene hydrocarbon seep deposits, which occur as isolated limestone outcrops within voluminous siliclastic mudstones of the Hawke's Bay region in the East Coast Basin, North Island, New Zealand. The fauna is dominated by molluscs but also includes zootaxa from at least five other phyla. Three new mollusc species (one provannid gastropod and two mytilid bivalves) have already been formally described from the specimen collections used in this study. Several more new taxa (ca. 10 new species and at least one new genus) also are earmarked for future work, as well as emended descriptions and new records of known species. Most known New Zealand fossil seep deposits are strongly bioturbated, and the shells contained within them are commonly bioeroded. The trace fossil content also is evaluated, adding to a relative paucity of such work on fossil hydrocarbon seep deposits. Comparison of the New Zealand Miocene seep fossil fauna with temporally (Miocene-age) and spatially (circum-Pacific) analogous fossil seep faunas has allowed initial palaeobiogeographical evaluation of New Zealand fossil seeps. It was found that, when analogous localities were grouped *a priori* into geographical regions and provinces, there was a greater correlation between their taxonomic similarity to the New Zealand fossil seep fauna and the age of the deposits, rather than to their geographical location. Hydrocarbon seeps, especially those occurring bathyally and deeper (the most common setting for their occurrences today and in the past), are widely considered as refugia. However, our palaeobiogeographical analysis supports the hypothesis that seep faunas, and faunas in similar environments (e.g. hydrothermal vents), have been subject to constant change since they first began to colonize and adapt to life in these habitats.

**GEOLOGY, GEOCHRONOLOGY AND GEOCHEMISTRY OF THE GLENROY COMPLEX
AND ADJACENT PLUTONS, NELSON: FRAGMENTS OF NORTHERN FIORDLAND?**

M.W. Sagar¹, J.M. Palin¹ & V. Toy¹

¹Dept. of Geology, University of Otago, PO Box 56, Dunedin.
sagma887@student.otago.ac.nz

In the Matakaitaki and Glenroy River valleys south of Murchison, SE Nelson, high-grade gneisses and granitic plutons outcrop over an area of ~50 km² adjacent to a major constraining bend on the Alpine Fault. Woodham Orthogneiss, Davis Creek Gneiss, Double Creek Orthogneiss and the Mt. Cann Formation collectively make up the Glenroy Complex. The hornblende-biotite dioritic Woodham Orthogneiss occasionally contains relict primary 2-pyroxene assemblages and exhibits no evidence of garnet granulite facies metamorphism. The biotite-muscovite Double Creek Orthogneiss intrudes the Woodham Orthogneiss and contains garnetiferous leucosomes. Davis Creek Gneiss is more heterogeneous, comprising leucocratic biotite, and intercalated biotite-garnet and hornblende-biotite quartzofeldspathic gneisses. The nature of contacts between the Davis Creek Gneiss and the Woodham or Double Creek orthogneisses are uncertain at present. Two granitoids are in contact with the Glenroy Complex: massive coarse-grained hornblende-biotite granite and medium-grained biotite diorite of the McKnee Pluton and the Mt Cann Granite.

LA-ICP-MS zircon U-Pb dating indicates that emplacement of the Woodham (125 ± 1 Ma) and Double Creek (120 ± 1 Ma) orthogneisses was coeval with emplacement of portions of the Western Fiordland Orthogneiss (WFO) and Separation Point Suite (SPS) in northern Fiordland. The Woodham and Double Creek orthogneisses also share compositional similarities with plutons of the WFO and SPS. Intrusion of the McKnee Pluton granite occurred at 222 ± 2 Ma – coincident (within error) with emplacement of the Mistake Diorite of the Mackay Intrusives in northern Fiordland. Furthermore, the whole-rock compositional diversity of the McKnee Pluton is similar to that of the Mackay Intrusives. Zircon U-Pb systematics of the Davis Creek Gneiss are more complicated, involving some combination of either a) inheritance of Paleozoic and Mesozoic zircons, emplacement and subsequent metamorphism and deformation, or b) derivation from a heterogeneous source and (?poly)metamorphism and deformation.

FORENSIC GEOSCIENCES : WHAT, HOW AND WHY

A. Sandiford

The Forensic Group, PO Box 17-317 Greenlane, Auckland.
Sandiford@theforensicgroup.co.nz

These days, the term 'forensic' is bandied about all over the media, from news items through to TV series such as *CSI*. The terms 'forensic' means relating to a court of law or something for public discussion or argumentation. It also relates to science and technology being used to establish facts for a court of law. In the adversarial court system, which we have in New Zealand, once that information is presented and accepted in court, it becomes evidence.

Forensic geosciences therefore relates to geosciences being presented in a legal arena. Although it may sound unusual, geosciences techniques are commonly applied in the legal arena.

This presentation will provide interesting examples of what types of geosciences have been presented, how they were used and why. Examples include paint damage to a superyacht, determining the age of a property, assisting with war crimes tribunals and identifying where illegal drugs have been cultivated.

A warning for those who are not routinely involved in forensic science: what you want to present to the court and what you are allowed to say as evidence may not always be the same thing...

**LESSONS FROM THE COURTROOM:
BAYESIAN INTERPRETATION OF GEOLOGICAL DATA**

A. Sandiford¹, N. Powell²

¹The Forensic Group Ltd, PO Box 17-317, Greenlane, Auckland.

²Forensic & Industrial Science Ltd, PO Box 67-087, Mt Eden, Auckland.
Sandiford@theforensicgroup.co.nz

In common with any other area of science, geological research involves acquisition and interpretation of numerical and observational data. The question arises as to what is the most appropriate way to interpret such data for the purposes of testing geological hypotheses.

Interpretation of scientific data using a Bayesian approach (formulating propositions and establishing a Likelihood Ratio) has been thrashed out in the Court system over many years to the point where, in many jurisdictions, any other method of data interpretation and evidence evaluation is no longer acceptable.

Our presentation will outline the basics of Bayesian methodology as applicable to geological data and provide examples of how data can be evaluated within such a framework to produce robust interpretations. Interpretation using a Bayesian framework is particularly useful as it can assist in avoiding irrational intuitive interpretation, inadvertent bias, or reliance on data of negligible probative value.

Bayesian methodology is widely applicable in geology but is underutilised. Its application to unresolved uncertainties in New Zealand regional geology has yielded several controversial counterintuitive results.

**NEW ZEALAND'S NEXT TOP MODEL: THE ROLE OF SOCIAL SCIENCE IN INTEGRATING
TSUNAMI MODELLING INTO LAND USE PLANNING**

W.S.A. Saunders^{1,2}, G. Prasetya² & G. Leonard¹

¹GNS Science, PO Box 30368, Lower Hutt

²Joint Centre of Disaster Research, Massey University, PO Box 756, Wellington.
w.saunders@gns.cri.nz

Social science research is providing a valuable resource in bridging the gap between tsunami modellers and land use planners. With a recent focus on the importance of tsunami modelling for planning evacuation zones and emergency management preparedness, land use planning issues also became apparent. New social science research is exploring the difficulties in integrating physical science models into land use planning, with a focus on tsunami.

This research seeks to understand and document the contrasting information requirements of planners, emergency managers and tsunami inundation modellers, and make recommendations on how modelling can be incorporated into land use planning at a local level. In doing so, the project is assisting the understanding amongst tsunami modellers, planners and emergency management officers when pursuing a common outcome – to reduce the risk of natural hazards to communities in New Zealand.

Using the social science methodological technique of Participatory Action Research, (PAR), the social scientist works *with* local planning staff, *for* planning staff i.e. staff are involved in the process of developing a framework and guidance for incorporating tsunami modelling into land use planning. Council staff become partners in the research process, rather than clients. This approach encourages the ownership, uptake, implementation, and promotion of the framework amongst planners within their own Council, and to other Council planning staff.

This presentation will provide: an overview of the project; the methodology used to understand land use planning and emergency management requirements and expectations; the findings from local government workshops; and present a preliminary framework which integrates the requirements of land use planners, emergency management officers, and tsunami inundation modellers.

SEARCH FOR TIME-VARYING SEISMIC PROPERTIES AFTER THE 2010 M7.1 DARFIELD EARTHQUAKE

M. Savage, C. Boese, Y. Behr, K. Jacobs, S. Karalliyadda, K. Unglert, S. Kufner, J. Johnson, B. Keats, E. Smith, J. Townend
Geophysical Institute, Victoria University of Wellington, New Zealand
Martha.Savage@vuw.ac.nz

The 4 September 2010 M7.1 Darfield earthquake is one of the biggest earthquakes to occur in New Zealand in recent years. It occurred within the GeoNet network of permanent seismometers and near to a temporary seismic array of borehole seismometers set up along the Alpine Fault. Similar sized earthquakes in other parts of the world have caused observable changes in distant seismicity and in isotropic and anisotropic seismic wave speeds in nearby regions. Victoria University staff and students have combined forces to try to search for similar temporal changes associated with the Darfield earthquake. So far, we have noticed that triggers on the Alpine Fault network increased from an average of 3 per day to over 13 on the first day after the earthquake. Similar increases within the network were seen after last year's Fiordland earthquake. We will also use GeoNet data to examine seismicity in other regions to see if small earthquakes may be triggered by the Darfield mainshock.

Using the USGS finite fault solution and the GeoNet earthquake catalogue, areas of positive change in the Coulomb failure function at a depth of 5 km are associated with higher numbers of aftershocks than regions of negative change. We have begun to examine cross correlations and auto correlations using seismic noise recorded on nearby GeoNet stations for periods of four months before and as long as possible after the earthquake to search for velocity changes. We also examine V_p/V_s ratios and shear wave splitting at permanent GeoNet stations. Preliminary results so far show no obvious temporal changes in average isotropic or anisotropic wave speed. We will search for families of repeating aftershocks to see if more subtle changes are present.

CRACK HEALING AFTER THE 2007 CHUETSU-OKI EARTHQUAKE IN JAPAN

M. Savage¹ & S. Ohmi²

¹ Institute of Geophysics, Victoria University of Wellington, PO Box 600, Wellington.

² Disaster Prevention Research Institute, Kyoto University, Japan

Martha.Savage@vuw.ac.nz

The 2007 Mw=6.7 Chuetsu-Oki earthquake occurred within a dense network of permanent seismometers, making it an excellent place to examine time variations of seismic properties. We analyse auto-correlated waveforms (ACF) to determine isotropic velocity variations. ACFs are computed from the band-pass filtered seismic noise recorded with each short-period seismometer for each day. Seismic anisotropy is measured via a multiple filter automatic shear wave splitting measurement technique applied to S phases from aftershocks to determine fast polarization (ϕ) of the initial wave and delay time (dt) between the two split shear waves. We have examined two stations, IZUMOZ and N.KZKF, whose S arrival times were determined by the JMA network operators, and which are both at the edge of the rupture area. Autocorrelation functions show a sharp jump in the phase shift (change of lag time) of 0.05 s immediately after the mainshock, followed by a decay to background levels over a period of one month. These changes are seen on several phases at different lag times after the main shock, and suggest isotropic velocity changes between the surface and reflectors at 8-10 km depth. Aftershocks allowed us to determine a change of splitting parameters over time. Average dt decreases by about 0.1 s after the mainshock, following a decay curve that is similar to that of the phase shifts in the ACFs. Both stations exhibit similar dt decays, and such decays are seen in earthquakes from several different sections of the aftershock zone. ϕ also shows a change in rotation that correlates with the time delay changes. We suggest that after the earthquake, cracks opened up below the stations to decrease isotropic velocities and increase anisotropy. Crack healing over a period of a month returned both the isotropic and anisotropic velocities to their background value.

**TECTONIC EVOLUTION OF THE WESTERN MARGIN OF THE WHAKATANE GRABEN
(TAUPO VOLCANIC ZONE)**

C.G. Scholz¹, J.V. Rowland¹, D.M. Gravley² & C.J.N. Wilson³

¹School of Environment, The University of Auckland, Private Bag 92019, Auckland.

²Geological Sciences, Canterbury University, Private Bag 4800, Christchurch

³SGEES, Victoria University, PO Box 600, Wellington
C.Scholz@auckland.ac.nz

Understanding the tectonic evolution of the Whakatane Graben (WG), which forms the northernmost portion of the Taupo Volcanic Zone (TVZ), is critical to constraining the setting of magmatism, volcanism and geothermal activity in the TVZ. Most published onshore WG studies have focused on the eastern margin. Here, we present preliminary field observations and structural data from the Matata Fault Block (MFB) and Maketu areas to help constrain the tectonic evolution of the counterpart western side of the WG.

The MFB is dominated by normal faults that dip to the southeast, but faults dipping to the northwest can also be found. The fault orientations and dip directions delineate a complex fault zone that has evolved from east to west as a series of blocks with differential slip (i.e. horst and graben) that increase in throw (up to an order of magnitude) towards the edge of the Rangitaiki Plains. Development of the horst blocks is demarcated by different contact relationships between the 61 ka Rotoiti/Rotoehu and older (up to 550 ka) pyroclastic deposits. In particular, the Rotoehu fall deposit locally overlies an erosional/non-depositional surface on top of 550 ka deposits, demonstrating that fault growth and horst development within the MFB must have occurred over several hundred kyr. Similar horst structures, but with less precise age control, have been documented from offshore seismic reflection data sets.

At Maketu, sedimentation patterns in Pleistocene sediments and subsequent fault structures imply that there was an older and broader WG prior to ~370 ka, when there was a major eastwards shift of the WG to its present position. New structural data being collected may help untangle this complex eastward migration of the rift structures, and provide a link to offshore seismic profiles.

**MECHANISMS OF PARTICLE SIZE REDUCTION AND EXTENT OF CATACLASTIC
DAMAGE ASSOCIATED WITH THE ALPINE FAULT AT WAIKUKUPA RIVER**

Hannah R. Scott, Virginia G. Toy, Richard J. Norris

Department of Geology, University of Otago.

Scoha945@student.otago.ac.nz

During fault slip localised to a principal slip surface, cataclasis results in the formation of a fault core of fine grained fault rocks which have undergone fragmentation and shape change. Simultaneously, microfractures propagate into a 'damage zone' surrounding the principal slip surface. Previous studies have defined a relationship between the damage zone and (1) confining pressure and temperature during fault slip, (2) fluid movement, and (3) fault displacement. In the cataclastic rocks, fragmentation of grains by different mechanism results in the development of distinct particle size distributions. Particle shapes, which have previously been examined in more detail in sedimentological and volcanological studies, may also provide insights into formation mechanisms of cataclasites. Both particle size and shape influence the permeability of the cataclastic zone, while macro- and microfractures within the damage zone will also provide off-fault permeability.

The Alpine Fault has a well developed damage zone which has formed during repeated faulting. The Waikukupa River provides a near continuous section of the cataclasites and damage zone in the fault hangingwall. We have documented this section, and analysed variation in particle size and shape at various distances away from the principal slip surface within this zone.

We observe a fractal distribution of particle sizes. There is evidence of two distinct slopes to the size distribution curves. Small (<10 microns) grains have a fractal distribution of $D_2 = 0.91$, while large grains have a fractal dimension of $D_2 = 2.8$. There is also a linear reduction in overall fractal dimension with increasing distance away from the fault surface.

DIFFERENTIAL ROLL-BACK OF THE PACIFIC PLATE BENEATH THE NORTH ISLAND, NEW ZEALAND OVER THE PAST 20 MYR

H. Seebeck^{1,2}, **A. Nicol**¹, **M. Giba**³, **J. R. Pettinga**², **J. J. Walsh**³

¹GNS Science, PO Box 30368, Lower Hutt, New Zealand.

²Dept. of Geological Sciences, University of Canterbury, PO Box 4800, Christchurch.

³Fault Analysis Group, UDC School of Geological Sciences, University College of Dublin.

h.seebeck@gns.cri.nz

We chart temporal changes in the strike and dip of the subducting Pacific Plate beneath the North Island of New Zealand. Temporal changes in the geometry of the subducted Pacific Plate have been estimated using a combination of intra-slab earthquakes and changes in the location of arc volcanism over the past 20 Myr. Seismicity data suggest that the average dip of the slab increases to the northeast, while the active volcanic arc is 70-100 km above the subducting plate, consistent with global compilations of subduction arc systems. By comparison, arc volcanoes >~5 Ma are not underlain by the subducting plate. As the subducting plate from which the arc volcanoes were derived is no longer beneath these ancient arcs we suggest that the Pacific Plate has steepened and rolled back to the east since 20 Ma. The rates of rollback have varied in space and time, being highest at the northern end of the Hikurangi Margin prior to 5 Ma. Differential rollback is inferred to have resulted in a 1°/Myr average rotation of the subducting plate that is attributed to the greater length and gravitational load of the slab to the north. Differential rollback may therefore account for between half and a quarter of the clockwise vertical-axis rotation in the over-riding Australian Plate. The remainder of upper plate rotations may be due to collision of buoyant crust at the southern end of the Hikurangi Margin.

FIJI AS A CONTINENTAL FRAGMENT

A. Segev¹, **M. Rybakov**¹ & **N. Mortimer**²

¹ Geological Survey of Israel, 30 Malkhe Israel St., Jerusalem, 95501 Israel.

²GNS Science, Private Bag 1930, Dunedin.

n.mortimer@gns.cri.nz

Geological studies of Fiji in the last few decades have emphasised Eocene to Recent intra-oceanic arc and arc-rifting geological events and have not revealed the presence of any pre-Eocene rocks, or isotopic or other indications of older non-volcanic basement. However, in older literature, there are references to Fiji as a piece of continental crust (e.g. Woolnough 1903, Rodda et al. 1967, Robertson 1967).

We have investigated Fiji using three contemporary open file “data models”: (1) satellite gravity-derived bathymetry (Smith & Sandwell 1997); (2) Raw gravity (Free Air) data (http://topex.ucsd.edu/WWW_html/mar_grav.html); and (3) the CRUST2 global crustal structure model (Mooney et al. 1998, Bassin et al. 2000). In turn, we have produced a new derived Bouguer gravity anomaly map.

The bathymetric Fiji platform lies in a water depth of < 1000 m and is some 400 x 200 km in size. This is broader than the volcanic Lau or Kermadec Ridges, and of similar dimensions to the Northland region. Prominent low Bouguer anomalies (+20 to -10 mGal) typify the Fiji platform, New Caledonia and northern Lord Howe Rise. CRUST2 shows a crustal thickness of >19 km for the entire Fiji platform, comparable to stretched and submerged parts of Zealandia such as Lord Howe Rise and Chatham Rise.

We suggest that there may actually be a buried fragment of mature continental crust beneath Fiji that exerted a major control on the cusp in the Eocene-Recent Kermadec-Tonga-Vitiaz arc, and speculate that it once belonged to Gondwanaland/Zealandia. From this point of view, schist and granitoid basement described from Viti Levu, Fiji is of interest and warrants new investigation.

**STRATIGRAPHIC AND STRUCTURAL EVOLUTION OF A NEOGENE FOREARC BASIN,
NORTHERN WAIRARAPA, NORTH ISLAND, NEW ZEALAND**

S. Seirafi, M. Hall & P. Rich

School of Geosciences, Building 28, Monash University, Clayton, VIC, AUS, 3800
shirin.seirafi@monash.edu.au

The late Pliocene and early Pleistocene succession of Northern Wairarapa, North Island, lies within the fore-arc region of the active convergent margin along New Zealand's east coast. Sediments exposed between the Waewaepa and Tararua Ranges comprise a mudstone dominated succession up to 1520 m thick, with minor sandstone and conglomerate, and two prominent limestones, one Waipipian and the other lower Nukumaruan in age. These sediments have been traced over three folds and two major faults, on the western upthrown side of which basement greywacke is exposed.

The appearance and disappearance of molluscs have been used as stage indicators and benthic foraminifera, which are extremely sensitive to environmental influences, have been used to determine the water depths during deposition. From stratigraphic analysis and paleontological analysis of both macro and micro fauna, a model is proposed in which the sediments were deposited during at least two significant sea level cycles. However, considering the basin is near an active plate boundary and with the recognition of a spectacular unconformity at the base of the Nukumaruan limestone, there is a strong possibility that rate of the subsidence and active folding may also have influenced deposition of these sediments.

KEY WORDS: New Zealand Wairarapa, Pliocene and early Pleistocene, stratigraphy, Basin, Waipipian, Nukumaruan, Limestone, Mudstone, Conglomerate, Greywacke, Molluscs, Benthic foraminifera, Sedimentation rate, Water Depth, Subsidence

3D GEOLOGICAL MODEL OF THE WAIRAKEI GEOTHERMAL FIELD

F. Sepulveda¹ & S. Alcaraz² & R. Lane³ &

M. Rosenberg² & A. Rae² & G. Bignall² & W. Mannington¹

¹Contact Energy Ltd, Private Bag 2001, Taupo, New Zealand

²GNS Science, Private Bag 2000, Taupo, New Zealand

³ARANZ Geo Limited, PO Box 3894, Christchurch, New Zealand
Fabian.Sepulveda@contactenergy.co.nz

A 3-D geology model of the Wairakei Geothermal Field has been developed using Leapfrog Geothermal, a 3-D modelling and visualisation software, through a collaborative effort between GNS Science, Contact Energy and ARANZ Geo. The Wairakei 3-D geological model is primarily based on drill-hole stratigraphy, but also contains additional constraints such as interpreted faults and anisotropy of stratigraphic units. By imposing these constraints, geoscientists have been able to test their conceptual understanding of the architecture of the Wairakei Geothermal Field.

The 3-D geological model of Wairakei has shown the following:

- Stratigraphic discontinuities are recurrent and increasingly significant with depth. Some stratigraphic markers like Wairakei Ignimbrite vary in thickness from > 1000 m to absent.
- Most deep stratigraphic discontinuities can be explained by NE-trending faults. However, stratigraphic offsets at East Wairakei (injection area) are also consistent with NNW-trending faults.

Having a 3-D platform for imaging the 3D geological model of Wairakei, in conjunction with other drill-hole parameters (e.g. hydrothermal alteration, feed zones), numerical models (e.g. temperature) and geophysical data (e.g. micro-seismicity, resistivity), has resulted in an improved ability to analyse multidisciplinary geothermal data, inspect the interplay between stratigraphy and reservoir characteristics, and identify drilling targets and predict geological conditions during well planning.

ARANZ Geo, with the input of Contact and GNS Science, are continuing with the development and refinement of geothermal-oriented software features such as:

- Creation and visualisation of 3-D numerical models of the Wairakei Geothermal System (e.g. TOUGH2) based on the 3-D geological model and available field data.
- Development of a drill hole planning tool.
- Integration with Geographical Information Systems.

The 3-D geological model of Wairakei has become a powerful tool to convey our understanding of the Wairakei Geothermal System to a wide range of technical and non-technical audiences.

SAHKE II: THE SECOND PHASE OF THE SEISMIC ARRAY – HIKURANGI MARGIN EXPERIMENT

A.Seward¹, **S.Henrys**¹, **R. Sutherland**¹, **M.Henderson**², **T.Stern**², **M.Savage**²,
H. Sato³, **D. Okaya**⁴

¹ GNS Science, P.O. Box 30368, Lower Hutt 5040, New Zealand

² SGEES, Victoria University of Wellington, New Zealand

³ Earthquake Research Institute, University of Tokyo, Japan

⁴ University of Southern California, USA.

a.seward@gns.cri.nz

GNS Science and Victoria University of Wellington in conjunction with the University of Tokyo (Earthquake Research Institute) and the University of California, is installing a dense array of seismometers across the Wellington – Wairarapa region of the lower North Island. This project consists of 2 main parts. The first part, SAHKE I, consisted of a series of seismometer arrays in the region between November 2009 and April 2010. These seismometers recorded local, regional, and teleseismic earthquakes in addition of offshore seismic airgun blasts. The second part of this experiment – SAHKE II - will take place between May and June 2011, when a dense transect line of seismometers will record signals from local seismic blasts. SAHKE II will consist of over 900 single-component seismometers, spaced ~100 m apart along a 80 km transect across the lower North Island, which will record signals from ~12 seismic blasts on the transect. This poster will describe how the new dataset will compliment the data acquired during SAHKE I. Forward modelling of the proposed SAHKE II experiment design demonstrates the resolution of velocity structure and image that we will obtain across the lower North Island.

CONCEPTUAL MODEL OF THE ORAKEI KORAKO GEOTHERMAL SYSTEM: INSIGHTS FROM RECENTLY ACQUIRED MT DATA

S. M. Sewell¹ & **J. O'Brien**¹

¹Mighty River Power, 283 Vaughan Road, Rotorua, 3010.

Steven.Sewell@mightyriver.co.nz

Recent acquisition of MT data over the Orakei Korako geothermal system has provided new insights into the nature of the system. 3D and 1D inversions of the MT data image a low resistivity zone that correlates well with smectite alteration encountered in the four Orakei Korako wells (OK1-4). A conceptual model of the system has been constructed based on combined interpretation of the 1D and 3D inversions, well and spring geochemistry, geology, geothermal alteration, temperature and pressure data from the four wells.

The Orakei Korako system appears to be only partially sealed by smectite clays. Cold, meteoric water percolates deep into the system from the north and west through the smectite clay cap, possibly fed by a large rhyolite dome at the surface in this area. The meteoric water mixes with the geothermal fluid deep in the system (to at least the depth of the wells ~1500m) resulting in a dilute, low Cl-high HCO₃, reservoir. A relatively narrow upflow of hot fluid around OK4 and OK1 is apparent in the MT inversions and well temperatures, and is probably the source of the majority of the surface features in the Orakei Korako area. Faults mapped in the Orakei Korako Tourist Area tap into this upflow, providing pathways for this fluid to rapidly ascend to the surface with essentially the same chemistry as is observed in the reservoir. Based on deep well temperatures and higher Cl contents, the OK2 well in the north-east appears to be closer to a postulated, deep high Cl source of geothermal fluid.

**REDEFINING THE WAITEMATA BASIN, NEW ZEALAND: A NEW TECTONIC,
MAGMATIC AND BASIN EVOLUTION MODEL AT A SUBDUCTION TERMINUS IN THE
SW PACIFIC**

P. Shane, L.J. Strachan & I. Smith
University of Auckland, Auckland 1142, New Zealand.
pa.shane@auckland.ac.nz

The early Miocene Waitemata Basin has long been described as an inter/intra-arc basin, formed between twin chains of arc volcanoes in Northland, New Zealand. However, deep-marine, polymict, volcanoclastic conglomerates within the basin reveal tectonic and magmatic signals that are not evident from neighboring volcanic edifices. The conglomerates were deposited by high-density turbidity currents and debris flows, and include single sediment cycle, mega-clasts of lava. These basaltic lavas have Ocean Island Basalt (OIB)-like geochemical affinities, and are precisely dated at 20 Ma by ^{40}Ar - ^{39}Ar methods. Their age and the occurrence of subordinate clasts derived from an ophiolitic nappe to the north, indicate the basin post-dates the initiation of collision in the wider region. Contemporaneous calc-alkaline volcanism did occur some 250 km NW of the basin. However, the conglomerates lack clasts of calc-alkaline/arc affinities indicating an absence of arc-like volcanism in the vicinity of the basin. Recent tectonic models for the SW Pacific region and mantle tomography highlight the importance of wholesale slab detachment in driving early Miocene calc-alkaline volcanism and basin development. Although such models provide a slab window for the eruption of non-arc OIB-like magmas, they would not explain their localized occurrence at the proposed leading edge of the tear (Waitemata Basin), rather than progressively along the entire length of the detachment (Northland), as seen in other detachment settings. In addition, OIB-like volcanism pre-dates the adjacent calc-alkaline volcanism on the margin of the basin, a transition that is the opposite of that found at other slab detachment settings. The occurrence of OIB-like volcanism is better explained by a lateral slab termination in the vicinity of the Waitemata Basin that allowed asthenospheric-derived magmas to erupt. The basin is inferred to have developed in response to asthenospheric upwelling and associated lithospheric extension, or deformation associated with a slab termination zone.

**PROPERTY RIGHTS OF GEOTHERMAL RESOURCES: ACCESS POLICY IN NEW ZEALAND
AND MAORI OWNERSHIP**

B. Sharp ¹ & S. Malafeh ²

¹Dept. of Economics, the University of Auckland, PO Box 92019, Auckland 1142

²Dept. of Economics, the University of Auckland, PO Box 92019, Auckland 1142
Sam.malafeh@auckland.ac.nz

Electricity is an essential element of any contemporary society and/or economy. Questions on where, and how efficiently, the available energy is being generated are becoming increasingly important. Secure electricity production is essential for economic growth. Higher fuel costs and recent international initiatives to tackle carbon emissions encourage the use of renewable resources like wind, solar, hydro, and geothermal for electricity generation. This paper focuses on the development of geothermal resources for electricity generation.

Resources can be located in private, community, or public lands. In New Zealand, there are good geothermal resources located on land owned by Maori. Tangible benefits may help to fast track development. However, geothermal development in New Zealand is complicated. Fragmented multiple landowners have access to identical geothermal reservoirs while the Crown claims the control of the resource. Local communities need to know the real value of the resources located beneath their land in order to be able to estimate the total economic benefits. Government rules and regulations have an impact on the value of these resources by changing the bundle of rights associated to those resources.

This paper reviews government's access policy to the geothermal resources and the impact of those policies on the value of the resource. It studies the impact of single, multiple, and co-managed tapping systems on the value of geothermal resources located on Maori land. The paper aims to identify the best policy that can increase the value of geothermal resources and therefore enhance the welfare of Maori landowners.

LAYER PARALLEL COMPRESSION OF MULTILAYER SYSTEMS: IN SEARCH OF THE MECHANISMS OF KINK-BAND FORMATION USING NUMERICAL MODELLING

A. Shelley¹ & J.P. Latham¹

¹Imperial College London, South Kensington Campus, London, SW7 2AZ, UK
adrian.shelley06@imperial.ac.uk

A number of theoretical, experimental and numerical models have addressed the phenomenon of multilayer buckling; however theory on formation of kink bands remains relatively untested using numerical models. One major issue in kink band formation is the role that a system's intrinsic anisotropy and interlayer friction plays. The Virtual Geoscience Simulation tools, a combined Finite Element/Discrete Element method, is used to model the behaviour of two-dimensional elastic multilayered systems under compression, exploring the possible mechanisms behind the formation of kink bands over other styles of folding. Models are set up to investigate the effects of intrinsic anisotropy, interlayer friction and initial perturbations on the buckling response of multilayers under compression. Initial model results show that sinusoidal buckles are the preferred mode of deformation in elastic mono- and bilaminates when Young's moduli of ~1-10GPa are used for the material properties, independent of interlayer friction and for a range of boundary conditions. Further models where other, non-rheological Young's moduli were used yielded results in which non-sinusoidal, kink-like structures formed, specifically for monolaminates with a high interlayer Mohr-Coulomb friction coefficient of ~0.8. These results suggest that particular mechanical and frictional conditions must be met in order to initiate the formation of kink bands.

ENSO AND PDO RECORDS FROM AUCKLAND MAARS

J. Shulmeister¹, D.C. Nobes², B. Striewski³, J. Soderholm¹

¹GPEM, University of Queensland, St Lucia 4072, QLD Australia.

²Dept. of Geological Sciences, University of Canterbury, Private Bag 4800, Christchurch, New Zealand.

Dept. of Mines and Petrol., Govern. of Western Australia, East Perth 6004, Australia
james.shulmeister@uq.edu.au

We present the results of spectral analyses of laminae records from a series of Auckland Maar Lakes covering the termination of the last glaciation and parts of the Holocene. Some of the records are quasi-annual while others are at close to decadal resolution. All the records display a similar pattern with long intervals of no spectral power interspersed with shorter, decadal to centennial scale intervals of strong spectral coherence. In all cases spectral power has periodicities in the 15-30 year range and at about 50-70 years consistent with Pacific Decadal Oscillation (PDO) periodicity. For quasi-annual records strong spectral power is present at 5-7 year and 2-3 year periods, consistent with El Nino Southern Oscillation (ENSO).

The laminae are diatomaceous and we argue that the records are driven by nutrient flux to the maar, limiting diatom productivity. Because of the basaltic lithology and closed catchment of the maars, a limiting nutrient is likely to be silica. The source of silica is advection to the maars by Aeolian processes. We therefore argue that laminae thicknesses are a proxy for wind flow.

The relationship between Auckland climate and both ENSO and the PDO are well investigated. There is a known relationship between -ve ENSO events and SW wind flow anomalies in three seasons, over the Auckland region. Similarly there appears to be a relationship between +ve PDO phases and (south) westerly flow over New Zealand. We postulate that the brief episodes of strong spectral coherence over the Auckland region coincide with in phase relationships between +ve PDO and -ve ENSO events. The brief interludes of strong spectral power suggest that either these relationships are non-stationary, or that a further external forcing is involved, or most likely a combination of these factors. The oldest of these events coincides with the Antarctic Cold Reversal and we postulate that the additional forcing may be sourced in the Southern Ocean

HIGH FLOWS OF HYDROTHERMAL FLUIDS IN TVZ GEOTHERMAL SYSTEMS: IMPLICATIONS FOR EPITHERMAL MINERALISATION

S. F. Simmons¹ & J. Rowland²

¹Hot Solutions Ltd, PO Box 32125, Devonport, North Shore City.

²School of Environment, University of Auckland, PB 92019, Auckland.
stuart@hotsolutions.co.nz

The active epithermal environment is characterized by two end-member hydrological conditions: 1) tortuous percolation networks with sufficient permeability to satisfy the condition for fluid convection; and 2) a simple vertical structure that focuses flow through decompressional boiling in the upflow zone of the system. The first condition involves fluid movement driven by buoyant hot water; fluid pathways evolve in response to mineral deposition, change in rheology, and on going mechanical deformation. High bulk permeability accounts for the large volume of zoned hydrothermal alteration that forms around the epithermal environment and the upflow zone of the system. The second condition is transitory and is the natural analogue to the geothermal well in which fluid flow is driven by the upward expansion of a two-phase column of boiling fluid. High-flux conduits conducive to epithermal vein formation only have to form episodically to account for the deposition and accumulation of large amounts of precious metal, but the timing of high flow conditions must be linked with the deep hydrothermal supply of gold and silver.

Waimangu geothermal system is one example where high flows of hydrothermal fluid developed; in this case it was due to dike intrusion and extension during the 1886 eruption of Mt Tarawera. The hot water discharge of Frying Pan Lake (100 – 120kg/s), which occupies the western part of Echo Crater, is the highest for a single thermal feature anywhere in the Taupo Volcanic Zone, with a flow rate and power output similar to geothermal production wells.

Epithermal ore body geometries are diverse and unpredictable in their occurrence, and they are products of highly efficient periods of hydrothermal heat and mass transfer. The capability for high fluid flow conditions to develop is a feature of all high temperature geothermal systems, and all systems are potential sites of epithermal ore formation.

STATIC DEFORMATION OF A UNIFORM HALF-SPACE DUE TO A VERY LONG TENSILE FAULT

Mahabir Singh¹ & Sarva Jit Singh²

¹CoE, D.C.R. University of Science & Technology, Murthal (Sonepat-131 039), India

²Former Professor of Mathematics, Maharshi Dayanand University, Rohtak (India)
msdhankhar@gmail.com

The Airy stress function for a long tensile fault of arbitrary dip and finite width buried in a homogenous, isotropic, perfectly elastic half-space is obtained. This Airy stress function is used to derive closed-form analytical expressions for the displacements and stresses at an arbitrary point of the half-space caused by a long vertical tensile fault of finite width. The variation of the displacement and stress fields with distance from the fault and with depth is studied numerically. Contour maps showing the displacement and stress fields around a long vertical tensile fault in a half-space are also presented.

The aim of the present paper is to study the two-dimensional deformation of a uniform half-space caused by a long tensile fault of finite width. The corresponding problem of a long dip-slip fault has been discussed by Freund and Barnett (1976) and Rani and Singh (1992). Although two-dimensional approximation is an oversimplification of the physical system, it is very useful in gaining insight into the relationship among various fault parameters and in improving understanding of the deformation (see, e.g., Savage, 1987). Moreover, there are faults which are sufficiently long and shallow that the two-dimensional approximation may be used. The two-dimensional solution obtained here is useful because of its considerable simplicity as compared to the three-dimensional solution given by Yang and Davis (1986). We begin with the closed-form expression for the Airy stress function for an arbitrary line source in a uniform half-space given by Rani et al. (1991). Analytic integration over the width of the fault yields the Airy stress function for a long tensile fault of arbitrary dip and finite width. The expressions for the displacements and stresses at any point of the half-space caused by a long vertical tensile fault follow immediately.

**USING BORON ISOTOPES AND INDIGENOUS KNOWLEDGE
TO TRACE WATER IN THE BAY OF PLENTY**

A. Slade^{1,2} & B. Whitehead²

¹The University of Auckland, School of Environment, 23 Symonds St., Auckland 1142

²The University of Auckland, Institute of Earth Science and Engineering,

58 Symonds St., Auckland 1142

a.slade@auckland.ac.nz

To identify where water sources originate in a regional hydrologic system this research combines scientific and indigenous information, by using boron isotope composition data and local knowledge. The study area is the Bay of Plenty, in the North Island of New Zealand and includes a variety of surface and groundwater features. In particular a natural spring, Te Wai U o Tuwharetoa, which is of great cultural significance to the local hapū and iwi. Local indigenous knowledge suggests that selected lakes are feeding this spring via underground rivers. The research presented concentrates on this life supporting spring and focuses on identifying the connection between it and bodies of water in the area. Using boron isotope composition data in conjunction with water quality parameters we create a spatial model to investigate the relationships between water signatures and use GIS to visualise them.

DEVORA: YEAR 2 OF DETERMINING VOLCANIC RISK IN AUCKLAND

E. Smid¹, J.M. Lindsay^{1,2} & G. Jolly³

¹IESE, University of Auckland, Private Bag 92019, Auckland.

²School of Environment, University of Auckland, Private Bag 92019, Auckland.

³GNS Science, Wairakei Research Centre, Private Bag 2200, Taupo.

e.smid@auckland.ac.nz

Auckland, New Zealand's largest city and a vital link in the country's economy, is built on the potentially active Auckland Volcanic Field (AVF). Since 2008, there has been a boost in research into the hazard and risk associated with the AVF through the multi-disciplinary, multi-agency DETERMINING Volcanic Risk in Auckland (DEVORA) research programme.

Petrological, geochemical and geochronological studies of AVF volcanoes have found interesting complexities. Rangitoto, for example, has erupted twice, at ~552 and ~504 calibrated years before present (BP). The tholeiitic nature and U-Th systematics of the second eruption suggest greater degrees of partial melting from a shallower mantle source than other AVF eruptives.

New eruptions affecting Auckland are being discovered through tephrochronology studies, constantly improving the frequency estimate for events impacting Auckland in the past. Probabilistic hazard modelling based on a revised age order for the AVF reveals no obvious spatio-temporal trends, although the 'flare up' of activity around 32 ky BP, recognised in earlier studies, is strongly evident, as well as an unexpected NE-SW trend of vents which may hint at a hitherto unknown arc-related control on the field.

A review of volcanic hazard models relevant to the AVF has been undertaken, and ash fall impact models for Auckland have been included into RiskScape. The next steps are to introduce pyroclastic density current models into RiskScape. An assessment of probabilistic volcanic hazard methodology and preliminary modelling of thresholds for evacuation decision-making based on a cost-benefit analysis have been completed.

A GIS-based mass evacuation assessment for the AVF revealed significant diurnal differences in evacuation demand, and highlighted areas of Auckland with high population:exit capacity ratios. Transportation modelling highlighted major difficulties with a southbound evacuation; evacuation within the region would alleviate these difficulties. Additionally, the DEVORA borehole database recently fully migrated to GNS Science's PETLAB database for permanent storage.

CHANGES IN SURFACE ACTIVITY OVER 150 YEARS AT TAUHARA GEOTHERMAL FIELD, TAUPO VOLCANIC ZONE, NEW ZEALAND

E. Smid¹ & B. Y. Lynne¹

¹Institute of Earth Science and Engineering, University of Auckland, Private Bag 92019, Auckland.
e.smid@auckland.ac.nz

The Tauhara Geothermal Field (TGF), located within the Taupo Volcanic Zone, New Zealand, is under proposed development for power generation. In order to be able to properly assess any post-exploitation environmental issues and to determine natural versus artificially-induced changes in surface activity, a thorough understanding of historical thermal activity and the establishment of a present-day baseline prior to power plant commissioning is essential.

To that end, approximately 400 active and extinct geothermal surface feature locations in the TGF were surveyed in late 2009. Active features include hot springs, steaming and warm ground, fumaroles, and mud pools. Evidence of historic activity included hydrothermal eruption craters, collapsed and subsiding ground, sinter and silica residue deposits, and the alteration of the local rocks via acidic steam condensate to kaolinite clay. The activity levels and locations of these features were compared to historical accounts to determine how the surface expression of the TGF has changed over the past 150 years. Initial results support the well-documented observation that more northern surface features have become extinct than in the south since the exploitation of the Wairakei Geothermal Field, located 2 km to the north of the TGF, began in the 1950's.

Comparison of the locations and activity levels of present-day and historic surface thermal activity provides a look into the deeper geothermal reservoir processes, as variations in thermal migration patterns and levels of thermal activity indicate changes in reservoir characteristics. In this way, tracking changes in surface activity contributes to our overall understanding of the behaviour of deep geothermal reservoirs.

PROCESSING PETROLEUM INDUSTRY MULTI-CHANNEL SEISMIC DATA FOR WATER COLUMN TARGETS

M.W Smillie & A.R. Gorman

Dept. of Geology, University of Otago, PO Box 56, Dunedin.
smima003@student.otago.ac.nz

Little is known concerning the fine structure of water masses associated with the Sub-tropical Front south of the South Island. Multi-channel seismic reflection data acquired perpendicular to the north-flowing Southland Current over the Great South Basin reveal acoustic reflections of thermo-haline boundaries from within the water column. A comparison of two petroleum industry data sets collected in 2006 (DUN-06 from the *Pacific Titan*) and 2008 (OMV-08 from the *Wavefield Inseis Discoverer II*), in close proximity to each other, enables preliminary temporal interpretations of the variability of the Southland Current. This study outlines the variation in processing flows required to enhance the reflections for the two surveys. Data processing was completed using *GLOBE Claritas* and included acoustic velocity analysis, stacking and migration.

EDGES DETECTION OF GEOPHYSICAL ANOMALIES OVER THE MOKAI GEOTHERMAL FIELD - A NEW TECHNIQUE TO EXTRACT ADDITIONAL INFORMATION ON GEOTHERMAL RESERVOIR FROM EXISTING GEOPHYSICAL DATA

Supri Soengkono

GNS Science Wairakei, Private Bag 2000, Taupo 3352
s.soengkono@gns.cri.nz

The Mokai geothermal field is located about 25km north-west of Taupo, Central North Island, New Zealand. The field was delineated by Schlumberger DC-resistivity surveys back in late 1970s – early 1980s. The follow-ups geological, geochemical, other geophysical investigations and exploratory drilling (early to late 1980s) confirmed the existence of a high temperature system at Mokai. The system is currently supplying thermal fluid to a power plant producing about 110 MW of electricity.

The edges detection of geophysical anomalies over the Mokai geothermal field was carried out using the so-called “Multi Scale Edge Detection” technique (also known as “worming”) developed in mid-2000s to help interpretations of aeromagnetic and gravity data for mineral explorations. It basically determines points where the potential field (gravity or magnetic) varies strongest, following upward continuation of gridded data to multiple levels to represent multiple depths. These points are connected to form “wiggly” vector lines, i.e. the “worms”. The worms are used to infer geological structures indicating edges of source bodies of the potential field.

Although the edges detection technique is originally developed for potential field data (gravity and magnetic), it can be used, rather “inappropriately”, for any gridded data such as resistivity or topography. In this case, the upward continuation process would act simply as a low-pass filter.

The edges detection of the Schlumberger resistivity data over Mokai isolates a sub-zone in the south-eastern corner of the low resistivity area identified back in early 1980s. This sub-zone, which encloses most production wells at Mokai, seems to represent the productive part of the Mokai reservoir. Details of some geological structures within the sub-zone are indicated by the edge detections of gravity and high resolution airborne magnetic anomalies.

EXPERIMENTAL SIMULATION OF GREYWACKE-FLUID INTERACTION UNDER GEOTHERMAL CONDITIONS

R. Sonney^{1,2}, B.W. Mountain¹ & G. Bignall¹

¹Institute of Geological and Nuclear Sciences, Wairakei.

²Swiss Laboratory for Geothermics, University of Neuchâtel, Switzerland.
r.sonney@gns.cri.nz
romain.sonney@unine.ch

A continuous-flow system has been used to react distilled water with coarsely-crushed greywacke at a temperature and pressure of 25 - 210°C and 35 bars. This preliminary experiment allows determination of the rate of saturation and equilibration of the rock with a fluid that is low in dissolved components. The greywacke is a feldspathic litharenite, sourced from Waotu Quarry, Putaruru, and belongs to the Late Jurassic Manaia Hill Group of the Waipa Supergroup. At a temperature of 25°C and 1 ml/hr, reacted fluid samples contained measureable concentrations of Ca and Mg (approximately 5 and 1.3 mg/kg, respectively), due to either carbonate dissolution or cation exchange with clay minerals. During initial stages of the flow experiment, the pH increased up to 9 and thereafter remained stable. Minor silicate mineral dissolution explains the small concentrations of Al, Na, K and SiO₂ measured. Upon temperature increase to 210°C, SiO₂ concentrations increased up to 320 mg/kg ($T_{\text{quartz (Fournier)}} = 216^\circ\text{C}$) after two days. This was accompanied by increases in Na, K and Al and decreases to below detection limit of Mg and initially of Ca and Sr. The pH stabilised at approximately 7.5 over several days. These changes are attributed to the rapid equilibration of quartz accompanied by the precipitation and equilibration with a Ca-Mg bearing aluminosilicate, most likely smectite. Finally, the flow rate was set at 0.5 ml/hr producing changes in greywacke-fluid equilibria. The results of the rock-fluid interaction experiments will enhance our understanding of formation scaling mechanisms in greywacke-hosted reservoirs of the Taupo Volcanic Zone, with future experiments at elevated temperature (>300°C) - pressure conditions designed to test fluid extraction / injection and rock interactions as part of the Foundation for Research Science and Technology (PROJ-20199-GEO-GNS programme, “Harnessing New Zealand’s Geothermal Resources: Hotter and Deeper”).

**HEAT AND MASS TRANSFER BENEATH THE TAUPO VOLCANIC ZONE BASED ON
EVIDENCE FROM THE MORC'05 SEISMIC EXPERIMENT**

Tim Stern and Adrian Benson
Institute of Geophysics
Victoria University of Wellington
tim.stern@vuw.ac.nz

A new crust and upper-mantle model for the Taupo Volcanic Zone of New Zealand is presented based on data from an active-source seismic experiment (MORC). Nine \sim 0.4 - 1.3 tonne dynamite shots were recorded on \sim 700 seismographs spaced along a 120 km long array. The array ran from Bennydale in the King Country to 30 km east of Taupo. One of the most important new discoveries of the MORC project is a lower-crust "rift-pillow" of rocks where the P-wave seismic velocity (V_p) \sim 6.7-7 km/s. Wide-angle reflections show the top and bottom boundaries of the rift-pillow to be at depths of 15 and 25 km, respectively. Strong seismic reflections (termed P_mP_2) are recorded from a relatively short (10 -15 km-long) reflector at a depth of \sim 32 \pm 2 km. Ray-tracing shows the P_mP_2 reflector sits in the upper mantle, beneath the eastern margin of the TVZ and is directly beneath the active volcanic (andesite) front and geothermal fields. The relative amplitude of the P_mP_2 reflections indicates they are best explained by an interface across which there is a \sim 80% drop in the S-wave seismic velocity (V_s) and a modest (10%) drop in V_p . Such a change in wave-speeds is consistent with P_mP_2 representing the upper surface of a volume where the partial melt content may be as high as 12%. We propose this volume to be primitive basaltic melt from the mantle wedge. On the basis of our new data, and kinematic information on extension rates, we propose a model of heat and strain transfer to explain the relative distribution of heat output through the geothermal systems, and andesitic and rhyolitic volcanic centers within the TVZ.

**MANTLE DEFORMATION AND SURFACE PROCESSES IN OROGENIC AND TRANS-
TENSIONAL ZONES: FINITE ELEMENT EXPERIMENTS WITH APPLICATION TO
WESTERN NORTH ISLAND (NZ)**

Tim Stern¹, Greg Houseman² and Lynn Evans²
¹ Institute of Geophysics, Victoria University of Wellington
² Institute of Geophysics and Tectonics, University of Leeds, UK.
tim.stern@vuw.ac.nz

Mantle deformation is the primary driver of changes in continental surface elevation and rock uplift on spatial and time scales of \sim 100-300 km and 10-50 my respectively. Mantle instability most readily arises from shortening and thickening in orogenic zones. Another manner in which the continental mantle lithosphere becomes unstable is if it is quickly juxtaposed with a region where the mantle lithosphere is thinned or absent. If both processes occur in tandem – thickening then juxtaposition with a rifting region – then a highly unstable situation arises. Such a setting developed during late Tertiary times in the western North Island along the western boundary of what is now the Central Volcanic Region. Miocene shortening in the Taranaki fault zone was followed by Pliocene back-arc spreading in the Central Volcanic Region. We develop preliminary 2D models for convective removal of mantle lithosphere where the boundary conditions include both an initial thickening, and a free edge (i.e. adjacent to buoyant, low viscosity, asthenosphere) in the mantle portion of the lithosphere. Newtonian, temperature-dependent viscosity is assumed for these preliminary models, which are all carried out with dimensionless variables. An instability readily grows from the free-edge of our model and migrates inwards in a drip-like form. We find that the mantle lithosphere will laterally migrate \sim 200 km in 20 my if the viscosity at the top of the mantle lid is \sim 10²¹ Pa s. This provides a reasonable fit to geophysical data from western North Island data and the value of viscosity is similar to that required for other global localities (southern California, Alboran Sea). Understanding such processes is important for not only learning about fundamental properties of the earth's mantle, but also providing us with a framework to interpret basin and uplifted structures formed behind an evolving plate boundary.

THE APPLICATION OF VALUE MANAGEMENT & ENGINEERING TO GEOTHERMAL PROJECTS

D. Stevens

Parsons Brinckerhoff, Sydney
dstevens@pb.com.au

Value management (VM) is the most powerful and cogent tool in the project optimisation tool suite; it demonstrates to key stakeholders the relative importance of the key design objectives and the comparative merits of alternative courses of action on any project. It also ensures that an understanding of, ownership of, and commitment to the final design objectives are shared by all stakeholders.

Value engineering (VE) is a workshop process through which the client can demonstrate that the overall design objectives of the project (as identified in the value management workshop) are being provided at a minimum cost whilst maintaining the stated quality, safety, aesthetics, etc. through functional analysis. Savings can be identified, confirming value for money. Value engineering is more likely to occur at the detailed stage of design in the development of a project. Also a half day risk management workshop is held back-to-back to identify assess and manage risks associated with the value engineering outcomes.

The main difference between value management and value engineering is that the former is considered from the strategic point of view with the latter being the tactical.

THE GEONET PROJECT: DATA FOR RESEARCH INTO NEW ZEALAND'S NATURAL HAZARDS

M. Stevens & S. Page

GNS Science, PO Box 30368, Lower Hutt.
m.stevens@gns.cri.nz

GNS Science, through the GeoNet Project, has greatly improved monitoring of geological hazards in New Zealand and the collection of enhanced research data on the processes that cause earthquakes, volcanic eruptions and related effects.

GeoNet uses a wide variety of sensing equipment located throughout New Zealand. The New Zealand National Seismograph Networks accurately measure the location, magnitude, depth and other characteristics of earthquakes with enhanced volcano monitoring provided by the Regional Networks. In addition to seismometers capable of characterising tsunami-causing earthquakes, a growing network of tsunami gauges collect measurements of actual sea-level fluctuations. Over 250 strong-motion accelerographs measure the extremely high ground accelerations associated with large damaging earthquakes, yielding information on the performance of structures during earthquakes. The Global Positioning System (GPS) network highlights areas within the crust where strain is building up or being released.

The GeoNet Data Centre is responsible for the capture of all geophysical data streams from field instruments or third party sources, the basic processing of raw data and the maintenance of archives. GeoNet provides free access to hazards data and information through its website (www.geonet.org.nz). This ranges from basic earthquake reports and Volcanic Alert Bulletins, to the retrieval of fundamental data sets such as GPS Rinex files, earthquake hypocentre derivations and instrument waveform data. The GeoNet Team regularly liaise with users of the data and information to ensure they are aware of its scope and the mechanisms for its distribution or retrieval.

GeoNet hazards data and information helps strengthen scientific research capabilities, enabling scientists to pursue new avenues of research that will not only lead to a better knowledge of geological hazards, but also reinforce existing research.

**THE NEW NATIONAL SEISMIC HAZARD MODEL FOR NEW ZEALAND, AND THE
M_w7.1, 4 SEPTEMBER 2010 DARFIELD EARTHQUAKE**

M. Stirling¹, G. McVerry¹, M. Gerstenberger¹, N. Litchfield¹, R. Van Dissen¹, P. Barnes², K. Berryman¹, B. Bradley⁴, R. Buxton¹, K. Clark¹, K. Jacobs⁵, G. Lamarche², R. Langridge¹, A. Nicol¹, S. Nodder², J. Pettinga³, M. Reyners¹, D. Rhoades¹, W. Smith¹, P. Villamor¹, and L. Wallace¹

¹GNS Science, PO Box 30368, Lower Hutt.

²NIWA, Private Bag 14901, Wellington

³Department of Geology, University of Canterbury, Private Bag 4800, Christchurch

⁴College of Engineering, University of Canterbury, Private Bag 4800, Christchurch

⁵School of Geography, Environment and Earth Sciences, Victoria University of Wellington, Box 600, Wellington
m.stirling@gns.cri.nz

A team of earthquake geologists, seismologists and engineering seismologists from GNS Science, NIWA, University of Canterbury, and Victoria University of Wellington have collectively produced an update of the 2002 national probabilistic seismic hazard (PSH) model for New Zealand. The new model incorporates over 200 new onshore and offshore fault sources, and utilises newly developed New Zealand-based scaling relationships and methods for the parameterisation of the fault and subduction interface sources. The background seismicity model has also been updated to include new seismicity data, a new seismicity regionalisation, and improved methodology for calculation of the seismicity parameters. Background seismicity models allow for the occurrence of earthquakes away from the known fault sources, and are typically modelled as a grid of earthquake sources with rate parameters assigned from the historical seismicity catalogue.

The Greendale Fault, which ruptured during the M7.1, 4 September 2010 Darfield earthquake, was unknown prior to the earthquake. However, the earthquake was to some extent accounted for in the PSH model. The maximum magnitude assumed in the background seismicity model for the area of the earthquake is 7.2 (larger than the Darfield event), but the location and geometry of the fault are not represented. Deaggregations of the PSH model for Christchurch at return periods of 500 years and above show that M7-7.5 fault and background source-derived earthquakes at distances less than 40 km are important contributors to the hazard. Therefore, earthquakes similar to the Darfield event feature prominently in the PSH model, even though the Greendale Fault was not an explicit model input.

**INDEPENDENT ZIRCON CRYSTALLISATION HISTORIES REVEALED IN SYN-ERUPTED
RHYOLITE MAGMAS FROM THE 21.8 KA OKAREKA ERUPTION EPISODE, NEW
ZEALAND: INSIGHTS TO THE HETEROGENEITY OF CRYSTAL MUSH**

S. Storm¹, P. Shane¹, A.K. Schmitt², & J.M. Lindsay¹

¹School of Environment, The University of Auckland, Private Bag 92019, Auckland.

²Dept. of Earth and Space Sciences, University of California Los Angeles.
s.storm@auckland.ac.nz

The 21.8 ka Okareka eruption of Tarawera volcano, New Zealand, simultaneously ejected two mineralogically and geochemically distinct rhyolite magmas from the same conduit, triggered by basalt intrusion. ²³⁸U-²³⁰Th isotope analyses by SIMS on individual zircons from both magmas show a wide range of ages, indicating evolution >170 kyrs. We present crystal face analyses on unpolished zircons ('rims') which minimise the overlap onto different age domains and therefore sample the latest stage of crystal growth. Together with spot analyses on crystal interiors and continuous depth profiling these can be used to reconstruct the crystallisation histories of the two magmas (T1 and T3). Most rim ages range from ~21-78 ka (T1) and ~22-125 ka (T3). Thus, many crystals terminated growth tens of kyrs before eruption. Interior ages for the same crystals indicate age zonation and older ages that range from ~21-163 ka (T1) and ~20-198 ka (T3). This pushes the onset of zircon crystallization to at least ~150 kyrs before eruption. Overall, the zircon age distributions are polymodal and the two magma types display mostly disparate peaks in their respective age spectra. This demonstrates heterogeneity and independent crystallisation histories in parts of the mush zone. In addition to hiatuses in crystal growth prior to eruption, continuous depth profiling also reveals punctuated growth within crystals of up to 50 kyrs in duration. However, the hiatuses are not synchronous through the crystal population. Termination in crystal growth over periods of 1-88 kyrs prior to eruption, and non-synchronous growth hiatuses within crystals that erupted side-by-side in the same lapillus require meter-to centimeter-scale heterogeneity in the magma mush. A possible model could involve a network of melt-rich veins that controls zircon growth or stagnation due to localised contrasts and changes in melt temperature and chemistry induced by mafic intrusions throughout the life of the mush.

**HIGH FREQUENCY CLIMATIC CYCLICITY EXPRESSED IN DEEP-MARINE TURBIDITES:
THE SANTA BARBARA BASIN, CALIFORNIA**

Lorna J. Strachan *, **Bill McCaffrey** [§] and **Ben Kneller** [#]

* Geology Programme, School of Environment, University of Auckland.

[§]Earth Surface Science Institute, School of Earth & Environment, Leeds University, UK

[#]Department of Geology and Petroleum Geology, University of Aberdeen, UK
lorna.strachan@auckland.ac.nz

Deep marine turbidites can be deposited in the ultimate site of deposition for terrigenous sediment along the source to sink pathway. As a consequence determining sediment dispersal pathways, processes and triggers can be problematic. The aim of this presentation is to use a superbly dated, Holocene deep marine sediment core from the Santa Barbara Basin, California to highlight the link between terrestrial storminess, river flooding and turbidity current deposition.

Sedimentary and X-ray diffraction (XRD) analyses have been used to show two distinct turbidite types, distinguished on mineralogy, grain size, fossil and clay content. Type 1 turbidites are interpreted as remobilized shelf sediments of probable seismogenic origin, whilst Type 2 turbidites are thought to be linked to river-flood events, either directly as hyperpycnal flows or indirectly via remobilization from the shelf shortly after flooding ceased.

Analysis of Holocene sediments from the last 7 kyrs reveals that river-flood generated muddy turbidites form an integral part of the deep marine Santa Barbara Basin record. The distribution of river-flood generated turbidites is characterised by distinct clustering of events lasting for approximately 800 years. Intervening periods are completely devoid of such events. This suggests that during the last 7kyrs, southern California has been prone to sub-millennial periods of intense terrestrial storminess, river flooding and linked turbidity current generation punctuated with periods of apparent quiescence.

Comparison of the distribution of Santa Barbara Basin flood-generated turbidite clusters to other climate proxies reveals an uncanny correlation with submillennial North Atlantic cycles and implies a climate link between the East Pacific and North Atlantic.

UPDATED REGIONAL PALEO GEOGRAPHIES FOR THE TARANAKI BASIN

D.P. Strogen, K.J. Bland, J.R. Baur and P.R. King

GNS Science, PO Box 30368, Lower Hutt 5040.

d.strogen@gns.cri.nz

A reassessment of the regional paleogeographic evolution of the Taranaki Basin and surrounding areas has been undertaken, as part of a basin-wide seismic mapping project, within the ongoing FRST funded New Zealand's Petroleum Resources programme. A set of 31 maps have been produced that span the time from the Late Cretaceous through to the present day.

These maps synthesise both paleobathymetric and paleofacies data, expanding on those from previous studies and incorporating significant new data. Inputs include paleogeographic maps from a large number of existing studies, a new compilation of biostratigraphic and bathymetric data from over 200 wells in and around the Taranaki Basin as well as information from outcrops surrounding the basin, from both the literature and new QMAP data. In addition, in the Kupe and Central Graben areas, in the southern part of the Taranaki Basin, detailed new seismic attribute mapping is used to better constrain paleofacies in areas away from wells.

The maps and their constituent data, which are assembled in GIS, capture the most important aspects of the tectonic and sedimentary evolution of the Taranaki Basin and form the basis for ongoing detailed paleofacies mapping and basin modelling studies. The aim is to provide at least one paleogeographic reconstruction for every sequence bounded by mapped seismic reflectors, and where possible or necessary construct additional maps to capture major changes in facies or paleobathymetry within sequences.

The suite of paleogeographic maps is presented, and the evolution of the Taranaki Basin is discussed, highlighting major differences with previous studies. Insights gained into the overall regional tectono-stratigraphic evolution, such as the timing of fault movements, extent and causes of major unconformities and interpretation of subsidence history and sediment supply are also discussed.

THE FAREWELL FORMATION RESERVOIR FAIRWAY: A STUDY OF PALEOCENE BIOSTRATIGRAPHY, FACIES DEVELOPMENT AND RESERVOIR QUALITY IN THE TARANAKI BASIN

D.P. Strogon, L. Roncaglia & E.R. Crouch
GNS Science, PO Box 30368, Lower Hutt 5040.
d.strogon@gns.cri.nz

The Farewell Formation is a proven hydrocarbon reservoir fairway of Paleocene age in the Taranaki Basin. This project aims to develop a depositional model for the formation and its lateral correlatives, combining biostratigraphy and palynofacies interpretation, seismic reflection data, core descriptions, petrophysical log data and petrography. This work is part of the ongoing FRST-funded New Zealand's Petroleum Resources programme.

The initial phase of the study focused on a proximal to distal correlation of five wells, from Kupe South-5 in the southeast through Tui-1, to Tane-1 in the northwest. A review of Teurian-Waipawan (Paleocene–Early Eocene) dinoflagellate cyst distribution in the five wells was undertaken in order to better constrain the age of the Farewell Formation and assess the potential for enhanced biostratigraphic resolution within the Teurian. Initial results show that the upper and lower Teurian boundaries are well defined in the wells and several key intra-Teurian events are identified.

A pilot palynofacies study was carried out on well Tui-1 to help constrain the paleo-environmental interpretation. All residues contain abundant kerogen, which is mostly dominated by phytoclasts. The sediments were deposited in a nearshore marginal marine environment under oxic to dysoxic water conditions suggesting good ventilation in the water column, which was characterized by relatively high terrestrial/fresh water influx.

Key fluvial, coastal plain, marginal marine and shallow marine facies from the Farewell Formation are illustrated, using data from core and corresponding wireline log signatures, as well as examples from outcrop studies. Facies development is discussed in terms of the regional paleogeography, as is a preliminary well correlation for the five study wells. A review of published petrographic data for the Farewell Formation is given, as are insights into facies and geographic controls on variations in sandstone composition and diagenesis.

A METHOD OF DETERMINING MATRIX PARAMETERS IN WELL-LOGGING INTERPRETATION

Benyu Su¹ and Yasuhiro Fujimitsu²

¹ Laboratory of Geothermics, Department of Earth Resources Engineering, Graduate School of Engineering, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka, 819-0395, Japan

² Laboratory of Geothermics, Department of Earth Resources Engineering, Faculty of Engineering, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka, 819-0395, Japan
subenyu@yahoo.cn

It is important to apply matrix parameters to the research of evaluating a reservoir and especially crucial to apply matrix parameters to the formations that are heterogeneous and whose lithology has distinct differences in different directions. Since various formations have various compositions, different formations should be endowed with their own different matrix parameters. As far as a qualified well-log interpretation is concerned, every matrix parameter of formation should be determined. In this study, a problem occurred in production a oilfield in western China is demonstrated as an example and the method of determining matrix parameters is applied to this analysis. Moreover, we pay much attention on the attributes of rocks and analyze thoroughly the problem encountered in well-log interpretation. First of all, we take advantage of crossplot skill to study the well-log data. And then geological lithology is analyzed deeply by well-logging data to solve the problem discovered in the well-logging. When the target stratum underwent the compaction of immature stage and diagenetic mineralization of sub-mature stage, the mineral with crystal water and structure water was produced, and the mineral made Compensated Neutron Log (CNL) value high abnormally. Secondly, the method of linear regression is adopted to ascertain the categories and ingredients of the rock. As the result, the volume density matrix parameter, acoustic matrix parameter and neutron parameter are determined.

**RE-ANALYSIS OF LOCAL GEOID UNDULATIONS ALONG DOUBTFUL SOUND,
FIORDLAND IN NEW ZEALAND**

M. Sugihara¹ & Y. Nishi¹

¹Geological Survey of Japan, AIST, Central 7, Tsukuba, 305-8567, Japan.
m.sugihara@aist.go.jp

Fiordland is a mountainous region where many fiords extend up to 30 km inland from the coast and there are many large lakes. Along the coast is the Alpine Fault which is the boundary between the Pacific and Australian plates. Previous gravity measurements show an elongated positive Bouguer anomaly of up to 200 mGal amplitude exists within the region, and lies parallel to the coast near the fault there are strong gravity gradients.

The presence of such long and narrow fiords and lakes which occupy large portions of the region suggest that surface ship continuous kinematic GPS measurement could be a potential method to detect geoid undulations, and determine gravity anomalies. Trial measurements were made at Doubtful Sound in 1996. The survey was carried out on a NW-SE track because it is normal to the orientation of the gravity anomaly. Recently the gravity anomalies along the survey line interest us: implications for incipient subduction (House et al., 2002) and the 2003 M7.2 Fiordland subduction earthquake. We re-analysed the surface ship GPS data.

The same track was used for the outgoing and returning legs to enable time-dependent components of sea level and errors in the observations to be evaluated. Data from an onshore tide gauge were used to determine tide-removed sea surface topography. The time-independent topography contains a dominant linear trend, which may be ascribed to the global geoid undulations. The residual components of the topography are thought to be local geoid undulations; a convex trend is seen in the central part, where clear positive gravity anomaly is observed. Land gravity data around the study area were converted using LSC method into map of geoid undulations, which were compared with the observed undulations. The convex trend is common qualitatively, however, different in amplitude. The surface ship GPS measurements detected the undulations of wavelength of several kilometres which are not inferred from the sparse land gravity data.

MANTLE UPWELLING, GONDWANA SUBDUCTION DEATH, AND THE GLOBAL GEOID

R. Sutherland¹, S. Spasojevic² & M. Gurnis²

¹GNS Science, PO Box 30368, Lower Hutt.

²California Institute of Technology, Pasadena, California, USA
r.sutherland@gns.cri.nz

A model of mantle upwelling following Cretaceous Gondwana subduction death is able to explain diverse observations of anomalous topography in the Southern Ocean, the subsidence history of NZ basins, and a very large geoid low near the Ross Sea [Geology 2010 doi: 10.1130/G30613.1]. A search through adjustable model parameters reveals a viscosity contrast of 100 is required between the upper and lower mantle, and the absolute viscosity of the lower mantle must be 10^{23} Pa s [JGR 2010, doi:10.1029/2009JB006612]. We find a positive correlation between global geoid lows and negative shear-wave speed anomalies that we interpret as mid-mantle upwellings (400-1200 km depth). When global tomography datasets are used to quantitatively model instantaneous flow of Earth's mantle, we demonstrate that these upwellings at least partly explain the main geoid minima on Earth [Nature Geoscience 2010, doi: 10.1038/NGE0855]. We suggest that the process of subduction death is the ultimate cause of these upwellings and that they flow away over periods of c. 200 Ma.

CHARACTERISING POROUS GEOTHERMAL RESERVOIRES IN HUNGARY BY WELL TESTS

J. Szanyi¹, B. Kovács², B. Kóbor¹, T. Medgyes¹, A. Bálint¹, S. Kiss¹

¹Dept. of Mineralogy Geochem. and Petrology, University of Szeged, Szeged, Hungary

²Dept. of Hydrogeology, University of Miskolc, Miskolc-Egyetemváros, Hungary
szanyi@iif.u-szeged.hu

A geothermal gradient of 50 °C/km and 7,000 m thick sea sediment formations of three porous thermal aquifers make the Pannonian Basin the most potent geothermal field in Eastern-Europe. The porous formations contain water with temperatures up to 150 °C, while heat in fractured carbonated aquifers in the basement reaches 300 °C.

Thermal wells have been operated in Hungary for over 140 years, the Hódmezővásárhely and Szentes areas being the largest geothermal systems. 20 wells produce water with temperatures >60 °C, and 12 with temperatures >90 °C around Szentes. The total installed thermal power capacity is 60 MW_{th}. Reinjection has never been applied in the Szentes area. The Hódmezővásárhely system consists of 8 production and 2 injection wells, with a total installed thermal power capacity of 10 MW_{th}. Here, less than half of the water produced is reinjected.

In order to develop a sustainable reservoir management at Szentes and Hódmezővásárhely, long term well tests (3x1 month periods) and geophysical borehole-loggings were performed. Comparing current and earlier test results a significant sinking of reservoir potential was detected. Evaluation of pumping and injection test results show a low level clogging around injection wells, while cyclic pumping tests proved that there is hydraulic communication between the three porous thermal aquifers prompting for integrated management. We suggest that a new, sustainable reservoir management is needed if operators are to maintain, let alone increase production levels. At this stage of the project a numerical groundwater flow model calibrated with measurement results is under development. This model will enable the prediction of how the application of a production-reinjection management would affect the aquifers.

THE EFFECT OF CO₂ CONCENTRATION IN RESERVOIR SIMULATION AT TM FIELD.

M. Tamrin H.¹, Ade Sebastian S.¹ & Ali Ashat²

¹Petroleum Engineering Dept, Bandung Institute of Technology, Indonesia.

²Geothermal Program, Bandung Institute of Technology, Indonesia.
m.tamrinh@yahoo.com

The reservoir simulation for water dominated reservoir in TM Field has been conducted. Numerical simulator TOUGH2 with EOS1 model has been used. Natural state model using EOS1 shows quite good agreement between pressure and temperature profile compare to early exploration data.

However, based on production test data in TM Field, the fluid contains CO₂ as non condensable gas. In this study, we rerun the simulation using EOS2 and performed the sensitivity concentration of CO₂ towards pressure and temperature profile compare to the first model (EOS1) and early exploration data. The aim of this study is to determine the acceptable CO₂ concentration in TM Field even the engineer using EOS1 to run the simulation.

Keywords: CO₂, EOS2, Simulation

COSMIC-RAY MUON RADIOGRAPHY OF A VOLCANO

H.K.M. Tanaka

Earthquake Research Institute of the University of Tokyo, 1-1-1 Yayoi, Bunkyo,
Tokyo.
ht@riken.jp

The novel radiographic imaging method has been developed to survey the inhomogeneous structure of the crust using an azimuthally isotropic flux of cosmic-ray muons in the energy range up to a few TeV. The principle of the technique is that by measuring muon absorption along different nearly horizontal paths through a solid body, one can deduce the density distribution in the interior of the object. A muon detector is placed on a slope pointing toward a topographically prominent feature of interest, and there will be results for the volume located above the detector. The present method can also provide three dimensional images of the subsurface by making measurements from two or more different points. The method also has the limitations as follows: (a) it is limited to near-surface depths and strongly depends on the nature of the local topography; and (b) the method is limited to horizontal ranges of 2-3 km (which also limits the potential targets). However, the measurements would be ideal for studying the shallow structure of the crust at sites which cannot be well resolved because of their strong structural heterogeneity, and which therefore cannot have their structure determined by conventional electromagnetic or seismic techniques.

MATAURANGA TANGATA WHENUA O AOTEAROA

W. Tawhai

Te Whare Wananga o Awanuiarangi, Private Bag 1006, Whakatane
wiremu.tahwai@wananga.ac.nz

Matauranga is indigenous Maori knowledge that has been gathered over generations according to a set of principles, and is constantly being added to and amended. Weaved within the many strands of matauranga lie insights to many hazards and resources in New Zealand. Some fundamentals will be discussed: who are the tangata whenua?, what is the empirical construction of matauranga?, what are its boundaries and guiding principles?, similarities and differences with science, what is the role of cultural determinism on knowledge and its application? One of the key purposes of matauranga was to ensure that resources could be utilised and hazards managed in an inter-generational context.

INVESTIGATING EASTERN NORTH ISLAND STRATIGRAPHIC EVIDENCE FOR ANTARCTIC GLACIATION IN THE GREENHOUSE WORLD OF THE EARLY PALEOGENE

Michael J.S. Taylor¹, Campbell S. Nelson¹ & Chris J. Hollis²

¹Dept. of Earth & Ocean Sciences, University of Waikato, Private Bag 3105, Hamilton.

²GNS Science, PO Box 30368, Lower Hutt
mjst1@students.waikato.ac.nz

Early Paleogene (Paleocene-Eocene) climate was significantly warmer than today, with the poles generally considered to have been free of ice. These greenhouse conditions ended in the earliest Oligocene when the formation of the circum-Antarctic seaway between Antarctica and Australia had widened sufficiently to allow thermal isolation of the Antarctic continent and expansion of ice sheets to sea level. The associated invigorated Southern Ocean circulation patterns have been deemed responsible for formation of the Marshall Paraconformity (32-29 Ma), a prominent hiatus in many early Oligocene sedimentary sections in the wider New Zealand region.

However, some recent studies have suggested there may have been short periods of significant Antarctic glaciation prior to opening of the circum-Antarctic seaway, as early as late Paleocene (c. 58-57 Ma). This would imply that Antarctic ice sheet growth is less reliant on ocean heat transport than currently believed. The eastern North Island has several late Paleocene-aged rock sections that could record such early glaciations.

This study investigates the origin(s) of eastern North Island late Paleocene sedimentary sequences with the aim of determining whether any links can be made between the nature and disposition of the sediment facies and their bounding contacts with ice sheet growth on Antarctica affecting Southern Ocean current patterns. Most field work is complete, reported here, and laboratory analysis of samples is currently underway. In the studied sections the late Paleocene time interval is mainly represented by three lithologies: glauconitic sandstone and mudstone; organic-rich shale; and/or micritic limestone and dark mudstone. These lithologies may record sea-floor reworking or erosion by accelerated deep-water currents and intensified marine productivity due to upwelling, both of which could be linked ultimately to sea-level glaciation on Antarctica. Laboratory work, including petrographic, micropaleontologic, XRD, XRF, TEX₈₆, and stable isotope analyses, should give further insights into the validity of this hypothesis.

GPR and trenching resolve the geometry of the Matata Fault Zone contributing to the paleoseismic history of the Whakatane Graben

H. Taylor¹, J.V. Rowland², A.J. Dougherty³, P. Villamor⁴ & J.G. Begg⁴

¹Golder Associates NZ, PO Box 33-849, Takapuna, Auckland 0740, New Zealand

²Dept. of Geology University of Auckland, Private Bag 92019, Auckland 1142

³Institute of Earth Science and Engineering, Private Bag 92019, Auckland 1142

⁴GNS Science PO Box 30-368, Lower Hutt, New Zealand.

htaylor@golder.co.nz

The Rangitaiki Plains is a rapidly resurfacing environment dominated by unconsolidated sediment within the Whakatane Graben. The 1987 **M_L 6.5** Edgcombe earthquake and recent studies using Light Detection and Ranging (LiDAR) to produce high resolution Digital Elevation Maps (DEM), have led to an increased insight into faulting and fault distribution in the Rangitaiki Plains. The aim of this study is to contribute to a greater understanding of the paleoseismicity of the Matata Fault Zone, within the Rangitaiki Plains, using trenching and ground penetrating radar (GPR). GPR profiles to depths of 5 m were acquired using a 200MHz antenna across the two western most strands of the Matata Fault Zone. GPR profiles were converted to depth and migrated to enhance data; which showed discontinuous zones of horizons inferred to be fault zones. The western most strand of the Matata Fault Zone was then selected for a paleoseismic trench which reached depths of 5 m. Trenching and GPR were combined across this strand, GPR was run along the base of the trench to extend visibility. Analysis of trenching results show variable displacement rates during the late Holocene, including one rupture that produced a vertical offset of >1 m, consistent with an earthquake of **M**> 6.5. A long term slip rate of 2.9 ± 0.29 mm/yr was calculated over the two western most strands of the Matata Fault Zone. In addition to the GPR data acquired over the area designated for the trench, profiles were taken along the floor of the completed trench to extend visibility. This GPR imaged 4 m below the base of the trench and surface profiles, extending the paleoseismic fault history by one rupture event. The combination of trenching and GPR analysis has contributed to a greater understanding of the Matata Fault Zone, and of the whole Whakatane Graben.

THE CO-TIDAL MAPS OF THE OCEAN-TIDE LOADING IN NEW ZEALAND

R. Tenzer¹, V. Gladkikh¹

¹ National School of Surveying, University of Otago, PO Box 56, Dunedin, New Zealand.

Robert.Tenzer@otago.ac.nz

We investigate the vertical and horizontal crustal deformations due to the ocean tide in New Zealand. The computation of the ocean-tide loading is based on Farrell's method which utilizes the integral convolution of the ocean tide data and Green's functions over the world ocean surface. The ocean-tide loading is calculated for the tidal harmonic constituents M_2 , S_2 , N_2 , K_2 , K_1 , O_1 , P_1 , Q_1 , M_f and M_m and for the shallow-water components M_4 , MS_4 and MN_4 . The maps of the ocean tide (offshore) and of the ocean-tide loading (onshore) are compiled on a 5×5 arc-min geographical grid at the study area of New Zealand. The ocean tide model TPXO.7.2 is used for the numerical realization. This model was developed using the tide-gauge records and the altimetry data from TOPEX/Poseidon satellite mission. We adopt the body tide displacement Love numbers according to the PREM model of the Earth. The results reveal that the horizontal and vertical crustal motions due to the ocean tide in New Zealand are typically of the same order of magnitude. The maximum vertical motions reach 4.6 cm in the North Cape.

GLOBAL GRAVITY DATA FOR THE RECOVERY OF THE MOHO DENSITY INTERFACE

R. Tenzer¹, Hamayun²

¹ National School of Surveying, University of Otago, PO Box 56, Dunedin, New Zealand.

² DEOS, Delft University of Technology, Kluyverweg 1, 2629 HS Delft, The Netherlands.

Robert.Tenzer@otago.ac.nz

The Earth's gravity model EGM08 and the CRUST2.0 global crustal model are used to compute globally the step-wise topography corrected and consolidated crust components stripped gravity disturbances. The results are computed and presented globally on a 1×1 arc-deg geographical grid. The topographically corrected and crust-stripped gravity disturbances are used to recover the Moho density interface and to estimate the density contrast between the crust and upper mantle. The constant value of the crust-mantle density contrast is estimated to be globally of about 480 kg/m³. The gravimetric inverse problem is solved in order to recover the Moho density interface. The preliminary results of a regional study of the Moho depths beneath New Zealand and its continental shelf are presented and discussed.

A DIFFERENT VIEW OF OLIGOCENE OAMARU: PRELIMINARY SEQUENCE AND FACIES ANALYSIS

N. Thompson¹, K. Bassett¹ & C. Reid¹

¹Dept. Of Geological Sciences, University of Canterbury, PO Box 4800, Christchurch.
nicholas.thompson@pg.canterbury.ac.nz

The nature and origin of unconformities, particularly the Marshall Paraconformity, found in Oligocene deposits around Oamaru have been a matter of contention for many years. Correlation of these surfaces has always been difficult as they show significant lateral variation both in the duration of the hiatus and in the nature of the surface itself. Using a sequence stratigraphic framework we can see through the nomenclature to the facies relationships, showing that the units are not simply stacked stratigraphic sections, but are in fact diachronous.

Outcrops of basal limestone (Ototara Limestone) at and around the coast vary considerably, being low or devoid of glauconite with considerable macrofossil variations relative to volcanic activity and associated palaeohighs. Inland they consist of calcareous siltstone with higher glauconite levels. Coastal sections of this limestone's upper contact display a prominent phosphatised karsted horizon, while inland this is a lightly karsted or bored submarine surface. Atop this, greensand (Kokoamu Greensand) grades into a second succession of limestone (Otekaike Limestone), both of which vary in composition throughout the basin, with variable glauconite content both at the coast and inland. To the north large cross-beds indicate localised high-energy facies whereas inland finer grained facies indicate deep water. Sediments overlying local karsted unconformities found within the upper limestone show small and rapid changes in glauconite content. A further karsted unconformity separates this limestone from a moderately to highly glauconitic brachiopod-rich greensand (Gee Greensand).

These variations in unit composition, thickness and unconformity character suggest differing responses to sea-level change as a result of local topographic highs. Facies changes and variations in karst surfaces through the basin, alongside minor unconformities that are located on palaeohighs, can be used for more detailed correlation leading to a better understanding of minor fluctuations in relative sea-level for reconstructing global sea-level curves for the Oligocene.

MODELING THE EVOLUTION OF A TRANSFORM FAULT IN THE MANTLE SECTION OF THE NEW CALDONIA OPHIOLITE

Sarah J. Titus¹ and Joshua Davis²

¹Dept. of Geology, Carleton College, Northfield MN 55057, USA
²Dept. of Mathematics, Carleton College, Northfield MN 55057, USA
stitus@carleton.edu

The Bogota Peninsula shear zone has been interpreted as a paleotransform fault preserved in the mantle section of the New Caledonia ophiolite. Detailed mapping shows that the strike of foliation rotates over a 50-km wide region from NW, to N, to NNE approaching a 3-km wide high strain core of the shear zone. This rotation is symmetric and recorded by other datasets including: (1) subhorizontal lineations that rotate with foliation, (2) pyroxenite dikes that demonstrate increasing separation between boudins towards the center of the shear zone, (3) the shape preferred orientation (SPO) of orthopyroxene that defines increasingly stronger and oblate fabrics, and (4) the lattice preferred orientation (LPO) of olivine, which rotates clockwise ahead of field lineations.

To characterize the evolution of this dextral transform fault, we develop a kinematic model constrained by field data. We use the olivine LPO to constrain the orientation of the shear plane. The rotation of foliation and lineation is used to empirically define three distinct domains within the shear zone: a farfield, nearfield, and high-strain center. Our model assumes that the shear zone localized during its development so that farfield features preserve the first increment of deformation and the center records the last increment. For each increment, we constrain the orientation of the finite strain ellipsoid using foliation and lineation while the magnitude is constrained the orthopyroxene SPO as well as stretches estimated from boudinaged pyroxenite dikes. This data-rich approach to modeling is challenging, but may ultimately provide more insight into the development of a transform fault at a deeper lithospheric level than is commonly observed.

LONG-LIVED SHEAR ZONES IN MANTLE LITHOSPHERE, DUN MOUNTAIN BELT

V. Toy¹, N. Barth¹, J. Scott¹, A. Walker², H. Scott¹, J. Newman³ & B. Tikoff⁴

¹Dept. of Geology, University of Otago, PO Box 56, Dunedin 9054, New Zealand.

²Dept. of Geosciences, Smith College, Northampton, MA 01063, USA

³Dept. of Geology & Geophysics, Texas A&M University, College Station, TX77843, USA

⁴Dept. of Geology & Geophysics, University of Wisconsin-Madison, WI53706, USA.
virginia.toy@otago.ac.nz

Shear zones observed within the Red Hills peridotite massif in the Permian Dun Mountain Ophiolite Belt (DMOB) remained active through various stages during its formation and emplacement. The middle layer of the massif (with respect to its pre-emplacement orientation) is composed of harzburgite with dunite bands, locally abundant clinopyroxene veins, and plagioclase. The latter were formed during late reactive melt migration associated with generation of MORB-composition melts, presumably accompanying decompression to the metamorphic plagioclase stability field (<8 kbar).

In the upper part of the plagioclase-bearing layer many of the clinopyroxene veins have been deformed into dextrally asymmetric, close to isoclinal folds. Magmatic plagioclase defines a spaced foliation axial planar to these folds. Near the base of the plagioclase-bearing layer, the plagioclase foliation is perpendicular to the layer boundary; with increasing original stratigraphic height, the foliation rotates to parallel to the layer boundary and the tectonite foliation becomes more pervasive. We interpret these structural patterns as representative of a massif-scale shear zone that accommodated top-to-the-N shear of the shallowest part of the massif over the lower lithospheric mantle, during initial uplift and passage of the late reactive melts. Melt presence may have focussed deformation in the plagioclase-bearing zone or vice-versa.

Intriguingly, within this high temperature shear zone, which two-pyroxene geothermometry suggests operated at 790-820°C, are 1) porphyroclastic peridotite mylonites formed by deformation at lower temperatures (660-700°C) and/or higher strain rates, and 2) an overprinting serpentinitised shear zone formed at much lower temperatures (<500-600°C) in the presence of fluids. In the latter zone, analysis of slickenfibres orientations on block surfaces with a variety of different orientations allows definition of two superimposed flow fields. One has kinematics compatible with shear during passage of the late reactive melt, and may therefore be an emplacement-related fabric, while a second reflects E-W-directed shear associated with fault reactivation during Cenozoic deformation.

WESTERN SAHKE MULTICHANNEL AND ONSHORE-OFFSHORE SEISMIC PROFILES: FIRST RESULTS FROM THE WANGANUI BASIN AND WELLINGTON REGION

**Brook Tozer¹, Tim Stern¹, Stuart Henrys², Rupert Sutherland², Anya Seward²,
Kimihito Mochizuki³, and SAHKE Field Deployment Team**

¹SGEES, Victoria University of Wellington.

²GNS Science, Lower Hutt.

³ERI, University of Tokyo, Japan.

brook_tozer@hotmail.com

SAHKE is a joint seismic experiment involving GNS Science, VUW, Earthquake Research Institute (University of Tokyo, Japan). SAHKE data were acquired between November 2009 and April 2010, in conjunction with a Crown Minerals (Ministry of Economic Development) funded marine seismic survey offshore Wairarapa. 480 km of marine multichannel seismic data were acquired on three profiles with two profiles on the western side of the North Island. SAHKE02 ran approximately between D'Urville Island to Kapiti Island and SAHKE03 from Kapiti Island to Wanganui City. We also installed independent seismic recorders over the southern North Island to record the offshore air gun blasts and thus form receiver gathers that would give us seismic refraction and wide-angle reflection data from the crust and upper mantle. Portable seismographs were also recorded from Wanganui city and along the Para Para road as far north as Taumaranui to specifically capture airgun energy from SAHKE03. Initial examination of the data shows that the airgun sources were recorded as visible events to maximum offset distances of at least 200 km. For example, a seismograph at Raurimu recorded air gun shots as both upper mantle reflections and refractions from (SAHKE 3). Initial examination of these data show Moho reflections as deep as 14 s two-way travel time, or about 42 km deep. This makes the crust beneath Wanganui Basin, an area about 100 m below sea level, as thick as that beneath the Southern Alps of central South Island.

SHIFTING ERUPTION STYLES DURING THE EMERGENCE OF AKAROA STRATO-SHIELD VOLCANO, BANKS PENINSULA, NEW ZEALAND

Aleysha Trent, Ben Kennedy & Eva Hartung

Dept. of Geology, University of Canterbury

AJT121@uclive.ac.nz

The uniquely eroded harbour of Akaroa volcano provides a rare opportunity to study the dissected core of the basaltic to trachytic strato-shield volcano. The early phase of both trachytic and basaltic volcanism and the later main phase of dominantly basaltic volcanism (9.6 – 8.6Ma) are well exposed in coastal sections. We aim to illustrate the volcanic processes of the diverse early phases of emergent volcanism and the transition into the main phase. We have built on previous research to produce detailed maps and stratigraphic logs of key extrusive and intrusive sequences. We further identify eruptive packages and their facies to identify eruptive centres, and correlate early stratigraphy.

Detailed mapping reveals a complex development of the strato-shield volcano with multiple volcanic centres identified with differing eruptive styles, chemistry and volume. Our research has revealed 8 eruptive centres, classified by cinder cones, lava flow directions, size and distribution of pyroclastics. Predominantly these centres are basaltic in composition consisting of (1) fine ash tuff layers containing small lapilli lithics (2) scoria cones steeply-dipping bed of well-sorted angular lapilli-sized scoria and juvenile bombs (3) voluminous 2 – 5m thick pahoehoe lava flows. These deposits demonstrate transitions in explosivity from initial vent clearing to Strombolian towards Hawaiian. A unique large trachytic centre at Onawe Peninsula shows (1) poorly sorted breccias tuffs, (2) normal graded accretionary lapilli-rich fine ash tuffs. These tuff units are widely dispersed (5 km²) predominantly to the southern and western sectors suggesting a surtseyan style eruption. The phreatomagmatic nature of these deposits and the dip of subsequent lava flows towards this centre suggest that it was topographically low during eruption.

The shifting styles of small volume volcanism indicate periodic leaks of magma occurred in different localities and that a large central shallow magma chamber had not developed during early phases of volcanism at Akaroa.

CORRELATING VARIATIONS IN GPS AND SHEAR-WAVE SPLITTING: IS THERE A COMMON SOURCE?

K. Unglert¹, M.K. Savage¹, N. Fournier², T. Ohkura³

¹SGEES, Victoria University, PO Box 600, Wellington.

² GNS Science, Wairakei Research Centre, Private Bag 2000, Taupo.

³ Aso Volcanological Lab., Kyoto Univ., Minami-Aso Aso Kumamoto 869-1404, Japan.

kathiunglert@gmail.com

Seismic anisotropy in upper crustal levels can be observed from shear-wave splitting. It is closely related to crack distribution and density via the orientation of fast polarisation ϕ and the delay time δt between the two perpendicular components of the original shear-wave, respectively. Monitoring of ϕ and δt has been proposed as a possible method to forecast volcanic eruptions, as the local stress field and with it the distribution and amount of anisotropy can change significantly, for example due to magma intrusion. Another observable result of variations in stress can be deformation measured by GPS stations. We investigate the questions of how variations in seismic anisotropy are connected to strain and stress changes and if we can observe and interpret this connection.

We performed shear-wave splitting analyses on local earthquakes around Aso Volcano, Japan, between 2001 and 2008. Two stations showed a significant change in ϕ in 2004-2005. By using only results from earthquake clusters with relatively stable epicentres, we excluded spatial variation as the cause of an apparent change of ϕ in time. We derived strain from GPS measurements in this area. To explain changes in strain and shear-wave splitting, we incorporate models from previous studies using seismic tomography and receiver functions into stress modelling. Fitting the models to both shear-wave splitting and strain estimates, we propose migration of magma in 2003 as a source for changes in seismic anisotropy and strain. This migration was associated with and followed by ash emission at Nakadake crater lake in 2003-2005. In conclusion, we confirm the connection of ϕ to maximum horizontal stress and strain, but also emphasise highly localised variations in both strain and ϕ due to unmodelled stresses or more complicated relationships between stress and strain.

**DYNAMICAL MODELING OF WET ASH CLOUDS: INSIGHTS FROM THE 27KA
ORUANUI SUPERERUPTION OF TAUPO VOLCANO, NEW ZEALAND**

A.R. Van Eaton¹, C.J.N. Wilson¹, M. Herzog², & J. McGregor³

¹SGEES, Victoria University of Wellington

²Centre for Atmospheric Sciences, University of Cambridge, UK.

³Institute of Geophysics, Victoria University of Wellington
alexa.vaneaton@vuw.ac.nz

Renewed interest in assessing the reliability of ash cloud forecasting has posed new questions regarding the methodologies used in and the limitations of available eruption cloud models. New Zealand's supereruptions represent end-member processes in terms of eruptive scale, and their reconstruction pushes the standard modeling techniques to their limits. This study presents results from simulations of eruption clouds generated during selected phases of the 27 ka Oruanui supereruption (Taupo volcano, New Zealand), using the non-hydrostatic cloud resolving model ATHAM (Active Tracer High resolution Atmospheric Model). Working within a range of volcanic and meteorological scenarios, sensitivity studies have identified likely ash cloud heights and thicknesses that characterize the water-rich eruptive phases. In particular, the role of water phase changes is investigated by varying water contents entrained from the surface (the eruption occurred through a large lake) and from atmospheric moisture. These controls on plume ascent provide insight into how large-scale, water-rich ash clouds interact with and intrude into a stratified atmosphere, with allowance for climatic conditions during the Last Glacial Maximum. Uncertainties arising from simplifying the interplay between plinian-style fall and co-ignimbrite input to hybrid ash clouds are addressed, and the broad scale limitations versus insights gained from simulating unobserved, multiphase events are discussed.

**SURFACE RUPTURE DISPLACEMENT ON THE GREENDALE FAULT DURING THE M_w
7.1 DARFIELD (CANTERBURY) EARTHQUAKE, NEW ZEALAND**

**R. Van Dissen¹, N. Litchfield¹, M. Quigley², P. Villamor¹, D. Barrell¹, K. Furlong³,
T. Stahl², B. Duffy², E. Bilderback², D. Noble², D. Townsend¹, J. Begg¹, R. Jongens¹,
W. Ries¹, A. Klahn², H. Mackenzie², A. Smith², R. Nicol², S. Cox¹, K. Pedley² &
R. Langridge¹**

¹GNS Science, NZ; ²University of Canterbury, NZ; ³Penn State University, USA
r.vandissen@gns.cri.nz

Surface rupture of the previously unrecognized Greendale Fault extended west-east for ~29.5 km across gravel-dominated alluvial plains west of Christchurch, NZ, during the shallow (~10 km depth), M_w 7.1 Darfield Earthquake which struck at 4:35 am on 4 September 2010 (NZST). Surface rupture is predominantly dextral strike-slip, expressed on left-stepping, en echelon traces arrayed in elegant, though subtle, fashion across the pastoral landscape. The largest step-over is ~1 km wide, located ~6.5 km from the eastern end of surface rupture, with another 20 step-overs between 300 and 75 m wide, and numerous smaller ones. Push-up structures formed at most of these restraining left-steps. The western 5 km of surface trace swings in strike to the northwest and shows displacement of ~1 m dextral and ~1 m vertical, SW-side up. The latter produced avulsion of the Hororata River.

Numerous well-defined straight features (fences, roads, power lines, crop rows, irrigation ditches, etc.) were offset by the fault, allowing the amounts and styles of displacement to be measured with high precision at more than 100 localities along the full length of surface rupture. Along the central 8 km of surface rupture, dextral displacement exceeds 4 m (maximum of ~5 m) and is distributed across a 30 to 150 m wide deformation zone via Riedel shears, conjugate Riedel shears and, mainly, horizontal flexure (offset on discrete shears, where present, typically accounts for less than a quarter of total displacement). Average displacement over the full length of surface rupture is ~2.5 m.

In many places, vertical deformation along the fault trace is confined to localized bulging on the order of tens of centimetres high spread over several tens of metres width, and extends across a Late Pleistocene braidplain of subdued fluvial bars and channels of similar or greater topographic relief. Without distinct linear markers such as fences, we probably would have identified only ~70% of the surface rupture length. As fissures heal and bumps smooth out, the ability to discern the fault trace, without reference to man-made features, will diminish further. This has implications for future seismic hazard assessment in the region and the search for possible past Greendale-type ruptures elsewhere. So too does the observation that the Greendale Fault has a notably short surface rupture length for its surface rupture displacement (both maximum and average) and M_w, when compared to international datasets of historic surface rupture earthquakes.

DRIVERS OF FORAMINIFERAL EVOLUTION AND EXTINCTION IN THE DEEP SEA

L. Van Kerckhoven^{1,2} & B.W. Hayward²

¹School of Environment, University of Auckland, Private Bag 92019, Auckland.

²Geomarine Research, 49 Swainston Rd, St Johns, Auckland.

l.vankerckhoven@auckland.ac.nz

This PhD research aims to increase understanding of the causes of global evolution and extinction in the deep sea. This is addressed by focusing on the enigmatic extinction of a distinctive group of cosmopolitan deep-sea benthic foraminifera during the late Pliocene-Middle Pleistocene “Last Global Extinction” (LGE) (3 – 0.12 Ma). This so-called “Extinction Group”, comprising nearly 100 species from among others the Pleurostomellidae, Stilostomellidae, Plectofrondiculariidae, Glandulonodosariidae families (c. 25% of deep-sea foraminiferal diversity at that time) all shared a similar morphology of elongate, cylindrical and uniserial tests with small, specialised apertures.

To find out what type of change could have been so all-encompassing to decimate and wipe out this major group of foraminifera, we are documenting the history of the “Extinction Group” through the Cenozoic in a number of oceans. In this study, we present the results on the occurrence and abundance of the “Extinction Group” species at ODP Sites 689 (Southern Ocean) and 1211 (North Pacific Ocean). The data indicate good adaptation of the “Extinction Group” to the warm and less-oxygenated Greenhouse World oceans (65 – 33.5 Ma), and a gradual decrease in relative abundance and diversity towards Icehouse World conditions (33.5 Ma – present). The LGE itself was coeval with the pulsed expansion of the northern hemisphere ice cap, rendering deep-sea conditions colder and more oxygenated during increasingly severe glacials. The dominant hypothesis therefore, states that the decimation and final extinction of the “Extinction Group” was caused by the inability of the extinct taxa and/or their food supply, to cope with these large and rapid changes in the deep-sea environment. We use proxies to investigate the relative roles of a number of palaeoenvironmental factors in determining the abundance and taxonomic turnovers of our species within the “Extinction Group”.

MONITORING THERMOTOLERANT VEGETATION USING AERIAL AND GROUND-BASED DATA

S. M. van Manen¹, R. Reeves¹

¹GNS Science, Wairakei Research Centre, Private Bag 2000, Taupo 3352, New Zealand

s.vanmanen@gns.cri.nz

Geothermal ecosystems are of high conservation and scientific value and monitoring of thermotolerant vegetation is an important management tool to assess natural variations and changes resulting from development. This study examines the composition of vegetation at four plots located within the Taupo Volcanic Zone, New Zealand.

The Karapiti (KP) and Wairakei Thermal Valley (WTV) plots were previously surveyed in 1995 and 1997. New plots were established in Taupo at Ashwood Park (AP) and Broadlands Road Reserve (BR). Plots consisted of 5 transects of 20 m, sampling was done at 1m intervals using the Scott height-frequency method. Ground temperatures were measured at 10 and 100 cm depth and a pH analysis was done for every other site. Aerial thermal infrared data were collected using a FLIR camera. 25 vascular plant species (8 indigenous, 17 naturalised) and 49 non-vascular plant species were recorded. Two species are listed as at-risk. Five species make up the majority of the individuals, all of these have similar optimum temperatures and pH. The remaining species each contribute less than 5% of the total plant population. There is an inverse relationship between the average temperature of the plot and the number of species identified. KP and WTV have seen substantial (35.6 and 10.2 °C respectively) mean temperature decreases in the past 13 years resulting in ecosystem changes at both plots, although the at-risk *Kunzea ericoides* var. *microflora* (‘prostrate kanuka’) remains dominant. AP and BR were also dominated by prostrate kanuka. Little correlation was observed between aerial TIR data and vegetation or 10 cm temperatures, probably due to uncertainties in georeferencing of the aerial data.

This study highlights the response of plant communities and in particular prostrate kanuka to changes in temperature as well as providing baseline data to compare future changes against.

**ALTERNATING MAGMATIC AND PHREATOMAGMATIC ERUPTION STYLES OF THE
MT. GAMBIER VOLCANIC COMPLEX, NEWER VOLCANICS PROVINCE, S.E.
AUSTRALIA**

J. van Otterloo¹, R.A.F. Cas¹ & J.M. Castro¹

¹School of Geosciences, Monash University, Clayton, VIC 3800, Australia
Jozua.vanotterloo@monash.edu

The monogenetic Mount Gambier Volcanic Complex is the youngest (ca. 5000 yrs. BP) volcanic centre in the Newer Volcanics Province of south-eastern Australia. This intra-plate volcanic province, which has been active for the past 5 million years, is characterised by large tholeiitic and alkali basaltic lava flows as well as small monogenetic eruption centres consisting of maars, tuff rings and scoria and tuff cones.

Multiple eruption styles have been recorded in the deposits of the monogenetic alkali basaltic volcanic complex of Mount Gambier, which consists of WNW-ENE aligned maars and tuff cones and rings and a buried scoria cone. These eruption styles occurred in a wide range from purely magmatic (i.e. Hawaiian and Strombolian) to phreatomagmatic producing pyroclastic fallout, surge and flow deposits as well as massive lava flows. The different units and facies were described and based on stratigraphic relationships the chronology of these differing styles can be constrained showing multiple alternations in magmatic and phreatomagmatic styles occurring on a short time-scale. Results from high resolution geochemical analyses show that the volcanic centre can be divided in two parts (east and west) which were fed by different small-volume magma batches. Differences exist in alkalinity (basanites vs. *ne-hawaiiites*), MgO, Ni and Cr contents as well as LREE enrichment. However, the wide variety in eruption styles occurred at both parts of the complex, implying that the magmatic compositions did not affect the alternations in eruption styles and that other factors like initial volatile contents, magma ascent rates, temperatures and aquifer dynamics should be researched.

**AN OVERVIEW OF THE ENERGY-WATER QUALITY NEXUS IN THE UNITED STATES:
INSIGHTS FROM THE 2008 COAL ASH SPILL IN TENNESSE**

A. Vengosh

Division of Earth and Ocean Sciences, Nicholas School of Environment, Box
90227, Duke University, Durham, North Carolina, USA
vengosh@duke.edu

Over five hundred power plants nationwide generate approximately 130 million tons of coal combustion products (CCPs) each year, in which more than half is stored in 194 landfills and 161 holding ponds. The Clean Smokestacks Act was enacted to reduce emissions from coal-fired power plants through installation of scrubbers and selective catalytic reduction, aiming to cut emissions of sulfur, nitrogen and mercury. In addition, volatile elements are attached to the residual CCPs. Consequently; toxic metals concentrations in CCPs are extremely high and become mobile upon interaction of CCPs with aquatic solutions. The 2008 coal ash spill in Kingston, Tennessee, where approximately 4.1 million cubic meters of coal ash was spilled onto the surrounding land surface and into the adjacent Emory and Clinch Rivers, has demonstrated the possible impact of CCPs on the environment. An eighteen-month survey has investigated the impact of CCPs in the affected area in Kingston, TN. The study shows that some contaminants that are originated from CCPs such as arsenic, selenium, boron, and barium could be significant high in affected water and become a significant ecological hazard to the environment. For example, concentration of arsenic in the pore water from downstream river sediments reached up to 2,000 ppb due to the combination of high ash/water ratio and reducing conditions that enhance the mobilization of the non-charged arsenic species to the water. The notion that CCPs generates a direct threat to the aquatic systems through holding ponds, landfills, or even "beneficial use" in sites where CCPs could be exposed and interact with the ambient environment should become an additional factor in evaluating the cost of "cheap coal" and its impact on the environment.

THE 2010 DARFIELD (CANTERBURY) EARTHQUAKE AND IMPACTS: A RESEARCH OVERVIEW

Pilar Villamor¹, on behalf of the Science Response Teams²

¹GNS Science, PO Box 30368, Lower Hutt.

²GNS Science-University of Canterbury Fault Rupture Team, GNS Science Seismology Team, GNS Science-LINZ-University of Otago Geodetic Team, University of Canterbury-University of Auckland-Christchurch City Council-Tonkin & Taylor-GNS Science-University of Lincoln Geotechnical Engineering Team, Environment Canterbury-NIWA-GNS Science Hidrology Team, University of Canterbury-GNS Science-Opus International Social Science Team, University of Canterbury-University of Lincoln-GNS Science Rural Recovery Team, University of Canterbury-University of Auckland-GNS Science-Christchurch City Council-Department of Building and Housing-NIWA Buildings and Infrastructure Team.
p.villamor@gns.cri.nz

The M 7.1 Darfield earthquake initiated at 10 km depth, 30 km west of Christchurch on a reverse fault, followed, within seconds, by several metres of dextral (right lateral) displacement on the newly emergent Greendale Fault. Extensive damage consistent with MMI 7-8 occurred in Christchurch. Peak ground accelerations were 0.2-0.3 g in Christchurch city and 0.6-1.2 in the epicentral area, and strong shaking lasted about 15 seconds. Thousands of buildings were damaged by shaking, liquefaction and/or lateral spreading, and approximately 3000 houses require major repair or reconstruction. Total cost of damage is estimated at about 4 billion NZD.

The science and engineering response assessed the earthquake source, surface fault rupture, regional deformation, liquefaction, building damage, and socio-economic impacts. Rapid deployment of teams and acquisition of remotely sensed imagery (e.g., InSAR, LiDAR) will provide an invaluable wealth of data. The effective response benefited from excellent inter-agency communications and prior CDEM exercises.

Lessons learnt will provide a solid basis for decisions on rebuilding Christchurch and for future best practise elsewhere in New Zealand, as well as advancing scientific knowledge. Surface fault rupture data provides another calibration point for the NZ National Seismic Hazard Model, and the relationship between strong ground motions and building performance enables evaluation of seismic provisions in the building code. Data from extensive liquefaction and lateral spreading will better explain the selective liquefaction where only c. 20 % of the susceptible area liquefied. Assessment of the direct and indirect losses will provide a basis for discussion of what constitutes "acceptable risk" and "tolerable impact" in natural hazard events, and perhaps redefine the requirements for building on liquefiable soils in New Zealand. For scientists and engineers many aspects of the Darfield earthquake were expected, but for the public major misconceptions and fears remain, highlighting the need for improved communication of science.

INVESTIGATION OF FLUID MIGRATION PATHWAYS IN THE SHALLOW SUBSURFACE OF THE GREAT SOUTH BASIN, THROUGH THE USE OF HIGH RESOLUTION SEISMIC IMAGING OF FAULTING AND SEAFLOOR FEATURES.

G.P.D. Viskovic^{1,2}, A.R. Gorman² & T.Allan³

¹GNS Science, PO Box 30368, Lower Hutt.

²Dept. of Geology, Univ. of Otago, PO Box 56, Dunedin, 9054, New Zealand

³OMV New Zealand Limited, Level 10, Deloitte House, Wellington, New Zealand
p.viskovic@gns.cri.nz

The Great South Basin, located off the South Otago and Southland coastlines, is one of New Zealand's largest undeveloped offshore basins, covering over 85,000 km² and is known to have significant oil and gas prospects. Understanding the "plumbing" of the Great South Basin, through seismic imaging of fault and fracture systems, provides information on oil and gas migration pathways and the success of seals and traps within the basin.

Recent seismic data acquired in the Great South Basin have identified a series of raised sea floor features of unknown origin occurring in an arcuate trend west of the Toroa-1 well location. These features are up to 175 m high, extend for over 50 km, and appear to be structurally controlled. The features, collectively named the Toroa Dome Reef complex, are examined in this study for their probable links with basin fluid systems.

Reprocessing of high-resolution industry seismic data has improved resolution of the shallow sea floor features. Interpretations of these reprocessed lines provide basic information on the morphology of the Toroa Dome Reef Complex. Further reprocessing, including near-trace/far-trace stacks, examinations of amplitude and phase change, FX-space deconvolution and band-pass filtering, have confirmed that the features have variable size and structure but in all cases are much harder than the surrounding seabed. The reflectivity contrast of the seafloor features relative to the overlying water column is so great that wipe-out occurs below the structures, obscuring internal structures. The sea floor features are interpreted to be volcanic in origin, although the possibility that they consist of methanogenic carbonate is possible. Future work based around high-resolution seismic surveys and a dredge sampling program could solve remaining uncertainties about the reefs' origin.

HYDRATION OF A RHYOLITIC MAGMA BY SPHERULITE GROWTH

**F.W. von Aulock¹, A. R. L. Nichols², F. Wadsworth³, P. A. Ashwell¹, H. Tuffen⁴,
B. Kennedy¹**

¹ Dept. of Geological Sciences, University of Canterbury, PB 4800, Christchurch 8140

² Institute for Research on Earth Evolution (IFREE), JAMSTEC, Kanagawa, Japan.

³ Dept. of Geology, University of Leicester, Leicester LE1 7RH, United Kingdom.

³ Lancaster Environment Centre, Lancaster University, Lancaster, United Kingdom.
felix.vonAulock@pg.canterbury.ac.nz

During spherulite growth water enrichment occurs in the surrounding glass, but generally it is not assumed to play an important role in volcanic activity. Our new data on the influence of spherulite growth on the surrounding glass illustrates the magnitude and spatial distribution of water enrichment through cracks that accompany spherulite growth. We show that the water enrichment reaches far enough to cause the glass transition temperature and viscosity decrease significantly. Field evidence for flowing of initially static lava leads us to propose that glass hydration could lead to the remobilization of lava. We worked on a sample of spherulitic, perlitic rhyolitic glass from Ngongataha Dome, New Zealand. Perlitic cracks run through the whole rock and can be distinguished from cracks that originate at the spherulites and extend up to 2mm into the glass. Water distribution in the glass was imaged by Fourier-transform infrared spectroscopy. The images show that total water is enriched in the glass surrounding the spherulites and in the cracks emanating from them. Concentrations reach up to ~0.5 wt% close to the spherulites and their associated cracks and less than 0.25 wt% in glass more than 90µm from them. Measurements by thermal analysis showed that the hydration was separated into two degassing temperature peaks, one at around 360°C, the other at around 550°C. These are thought to belong to perlitization and spherulite growth and their associated hydration, respectively. The glass transition temperature, defined by the peak in specific heat capacity, is 726°C in the unhydrated glass, and 715°C in the hydrated glass, close to the spherulites and their cracks. In summary, cracks in the glass around spherulites double the concentration of water up to 2mm away from spherulites. This has implications for temperature, diffusion rate, and viscosity and could play a role in volcanic processes.

THE DEATH OF A STROMBOLIAN ERUPTION: EVIDENCE OF DIKE DRAINAGE FROM RED CRATER, TONGARIRO VOLCANO

F. Wadsworth¹, F.W. von Aulock², C. Bardsley, B. Kennedy², M. Branney¹

¹ Department of Geology, University of Leicester, Leicester LE1 7RH, U.K

² Dept. of Geological Sciences, University of Canterbury, PB 4800, Christchurch 8140
fbw1@leicester.ac.uk

We present data from a dyke in the wall of Red Crater, Tongariro volcano, that record the closing stages of an eruption. The 1.85ka eruption began with andesite effusion followed by Strombolian eruption of basaltic andesite. It terminated with withdrawal of basaltic andesite from a shallow level dyke accompanied by a last gasp of phreatic explosivity. The dyke is twice as wide within the upper poorly consolidated scoria as it is within underlying better consolidated brecciated lava. Textural analysis of crystallinities and vesicularities using >5mm vesicles reveals three texturally distinct facies. (1) A glassy marginal facies with 12% vesicularity, margin-parallel flow banding and fabric defined by a preferred orientation of small phenocrysts (20-30% vol.). (2) A fully crystalline lower central zone with phenocrysts (50% vol.) randomly orientated and variably elongate vesicles (32% vol.). (3) An upper, almost completely crystalline central facies with subhorizontal flow banding arranged in en-echelon arrays, subhorizontally orientated phenocrysts (45-50% vol.) and patchy development of sub-spherical vesicles (vesicularity varies from 18-24% vol.). Coating the evacuated dyke interior is 1-2m finely laminated, fine-grained palagonitized ash. We interpret the three facies to correspond to three phases of magma movement. (1) is related to rapid freezing against the dyke margins during vertical eruption. (2) relates to a waning eruption during which the dyke widened. (3) records the draining body of magma in retreat, during which the magma level stepped inward, preserving subhorizontal, 0.3-0.5m wide "bathtub rings" on the interior wall of the dyke marginal zone. The rings occur 2m above a narrowing of the dyke which possibly suggests that vertical magma drainage was limited and the dip of the dyke suggests draining probably had a lateral component toward the centre of the crater. The additional presence of spherical vesicles indicates a possible period of magma stagnation and residual degassing.

MEGA-TSUNAMI: PLAUSIBLE EXPLANATION OF PUZZLING PEBBLES ON PITT ISLAND?

R. Clel Wallace¹ & Nicky J. Banks-Wallace²

¹ Soil & Earth Sciences, Massey University, Private Bag 11 222, Palmerston North.

² Turakina Maori Girls' College, Marton, 4710.

r.c.wallace@massey.ac.nz

As part of an ongoing project investigating marine terraces on Pitt Island, Chatham Islands, a stratum of pebbles has been identified. The stratum occurs near the top of thick, silty and or peaty coverbeds that rest upon gravels, that in turn unconformably overlie pre-Quaternary volcanics, volcanoclastics and/or silty sandstones.

The salient features of the pebble horizon are that:

- (1) it is dominated by pebbles and cobbles,
- (2) it is consistently 120 – 180 mm deep on all the terraces where it occurs,
- (3) it is found on six terraces of various, but distinctly different, heights, clustering at c.1m, 5-6m, 7-8m, 10-12m, 25-27m and 40-43m a.s.l.,
- (4) the clasts are dominantly of a local volcanic provenance, but minor or rare schist, sandstone, quartzite, and gneiss clasts, as well as bone and shell fragments, also occur,
- (5) the weight of the pebbles (kg/m^2), generally decreases with height, and
- (6) the size of clasts decreases with height.

This pebble horizon could result from (1) marine mammals regurgitating pebbles, (2) human activity, (3) storm activity, (4) aeolian deflation of a landscape, or (5) a tsunami. For various reasons a tsunami is considered the most plausible explanation and it is concluded that a mega-tsunami is the most likely cause of this pebble horizon.

AN EXPERIMENT TO MEASURE RESISTIVITY CHANGES PRODUCED BY GEOTHERMAL FLUID RE-INJECTION USING REPEAT MAGNETOTELLURIC MEASUREMENTS – INITIAL TESTS FROM THE WAIRAKEI GEOTHERMAL FIELD, NEW ZEALAND.

E. Wallin¹, T.G. Caldwell¹, T. Bertrand¹, S.L. Bennie¹, D. Feucht² & G.R. Jiracek²

¹GNS Science, New Zealand.

²University of California-Berkeley, U.S.A.

³San Diego State University, U.S.A.

E.Wallin@gns.cri.nz

Magnetotelluric measurements used to determine electrical resistivity structure utilize small, naturally-occurring fluctuations of the earth's surface magnetic field as a signal source. The ability to achieve repeatable magnetotelluric (MT) data in a high electromagnetic noise environment such as a producing geothermal field must be established if MT measurements are going to be a useful tool for monitoring resistivity changes caused by fluid extraction or re-injection. A program of repeat MT measurements in the South-Karapiti area, at the southern margin of the Wairakei geothermal field, has been started to establish baseline data prior to re-injection commencing in this area. The effects of near-surface changes in the MT response, caused by seasonal groundwater changes or minor misalignments of measurement sensors, can be avoided by using a phase-tensor analysis of the MT data which is insensitive to the effects of such near surface changes. Initial phase tensor results from two campaigns of MT measurements conducted in April and August 2010 will be presented.

MAGNETOTELLURIC CHARACTERIZATION OF TE PUIA SPRINGS, EAST CAPE

E. Wallin & R. Reeves

GNS Science Wairakei, Private Bag 2000, Taupo 3352

e.wallin@gns.cri.nz

13 magnetotelluric (MT) and 23 audiomagnetotelluric (AMT) soundings were acquired to help characterize the source and pathways of the low enthalpy geothermal water at Te Puia Springs north of Gisborne. While the geology is complicated by faulting and folding, there is limited resistivity contrast visible in the models. The apparent resistivities present in the AMT data occasionally rise to more than 100 Ωm , and fall as low as 1 Ωm , but are typically near 10 Ωm at all periods. These values are in agreement with resistivity logs from a hydrocarbon exploration well drilled just northwest of the springs. The AMT phases indicate primarily one dimensional resistivity structures, but data are limited by noise and low signal strength. The high frequency MT data exhibit apparent resistivity values similar to the AMT data. Magnetotelluric phase tensors suggest one and two dimensional structure and support north-northeast fault trends. Two dimensional modelling indicates a shallow localized region of higher resistivity just west of the springs possibly associated with the calcite sinter deposits. There are also resistive structures east of the springs that appear to correlate with faulting shown on the geologic map. A region of higher resistivity at 3 km depth likely corresponds to the interface between the East Coast Allochthon and the basement greywackes that are exposed on the western side of the Raukumara Peninsula and underlay the Cretaceous allochthon mudstones and siltstones. There is no reliable evidence in the model of a large source or pathway for the geothermal water. The ability to resolve geologic structures associated with the geothermal water is limited by lack of resistivity contrast.

STRATA DEVELOPMENT AND MORPHOLOGIC EVOLUTION OF THE WAIPAPOA RIVER MARGIN: INSIGHTS FROM SEDIMENTOLOGICAL, RADIOCHEMICAL AND GEOPHYSICAL DATA

J.P. Walsh¹, D.R. Corbett¹, A. Orpin², J. Kiker¹, A. Ogston³ & R. Hale³

¹Dept. of Geol. Sciences & ICSP, East Carolina University, Greenville, NC, USA.

²National Institute for Water and Atmospheric Research, Wellington.

³Oceanograph, University of Washington, Seattle, WA, USA.

walshj@ecu.edu

Margins with high sediment supply can produce thick sequences that contain detailed information on the controlling sedimentary processes; however, the stratigraphic record must be unravelled to understand the terrestrial and marine processes affecting sedimentation. As part of a recently initiated NSF Margins project, a combination of sediment-transport observations, coring and numerical modeling is being used on the Waipaoa River margin (New Zealand) to examine strata construction. This margin is a tectonically active and oceanographically energetic system with a significant sediment supply (~15 Mt/y). Results from recent research show that the Waipaoa fluvial sediment load is stored in shelf depocenters with significant material reaching the outer shelf and slope, filling relict relief and building thick (>40 m) deposits. A comprehensive dataset of core, chirp-seismic, and multibeam information explains how this complex system has developed. Decadal (²¹⁰Pb) and millennial (seismic-derived) sediment accumulation rates illustrate morphologic evolution of the margin while x-radiograph images provide insight into stratigraphic development. Integration of available data indicates that across- and off-shelf sediment transport and accumulation has occurred throughout the Holocene as tectonic activity has altered the margin. Variable but rapid (>0.3 cm/y) rates of sediment accumulation across the shelf suggest continuous and possibly accelerated accretion in discrete depositional areas.

A field effort was initiated in 2010 to examine strata development as it happens using in situ measurements from instrumented tripods and time-series coring. Results are preliminary, but multicores collected on three of four planned research cruises reveal that strata reflect a complex interplay of fluvial supply and oceanographic processes. Short-lived radionuclides (⁷Be, ²³⁴Th) data indicate deposition is consistent with decadal and millennial rates of storage. However, tripod measurements show short-term seabed dynamics (i.e., locally measured erosion) may differ dramatically from longer-term sedimentation patterns. The complete dataset will give valuable insights into the sequencing of sedimentary processes.

DO EARTHQUAKES GENERATE EM SIGNALS?

C. Walter, S. Onacha, P. Malin, E. Shalev and A. Lucas
IESE, University of Auckland, Private Bag 92019, New Zealand
c.walter@auckland.ac.nz

In recent years there has been significant interest in the seismoelectric effect which is the conversion of acoustic energy into electromagnetic energy. At the onset of the earthquake and at layer interfaces, it is postulated that the seismoelectric signal propagates at the speed of light and thus travels much faster than the acoustic wave. The focus has mainly been to use this method as a tool of predicting earthquakes. Our main objective is to study the possibility of using the seismoelectric effect to determine the origin time of an earthquake, establish an accurate velocity model and accurately locate microearthquakes. Another aspect of this research is to evaluate the possibility of detecting porous zones where seismic activity is postulated to generate fluid movement through porous medium. The displacement of pore fluid relative to the porous medium solid grains generates electromagnetic signals.

The Institute of Earth Science and Engineering (IESE) has installed electromagnetic coils in 3 different areas to investigate the seismoelectric effect. Two of the research areas (Krafla in Iceland and Wairakei in New Zealand) are in active geothermal fields where high microearthquake activity has been recorded. The other area of research is at the site of the San Andreas Fault Observatory at Depth (SAFOD) at Parkfield area on the active San Andreas Fault which is associated with repeating earthquakes.

This abstract presents the data from the Wairakei area. Preliminary data analysis has been carried out by band pass filtering and removing of the harmonics of the 50 Hz power line frequency. The initial results clearly show that electromagnetic signals accompany the seismic P and S waves (coseismic signal). Further data analysis involves the extraction of the seismoelectric signal generated at the onset of the earthquake and at interfaces from the coseismic signal and other 'noise' sources.

GEOCHEMISTRY OF PĀUA AS A PROXY OF PAST AND PRESENT NEW ZEALAND AND GLOBAL ENVIRONMENTAL CHANGE

R. White¹, J. Baker¹ & A. Whyte²
¹SGEES, Victoria University of Wellington, PO Box 600, Wellington.
²Ngati Kahungunu Iwi Incorporated, PO Box 2406, Hastings.

Nearshore New Zealand mollusca (shellfish) including pāua (*Haliotis iris*) have the potential to be important archives of environmental conditions and change. Ambient ocean chemistry is sequentially incorporated into the calcium carbonate (CaCO₃) shell during the life span of the mollusc providing a record of the chemical and physical changes of the environments they lived in. Previous studies on foraminifera and coral have shown that the substitution of magnesium for calcium (Mg/Ca ratio) during the formation of the CaCO₃ shell is directly correlated with ocean temperatures. Thus, it is hoped that the analysis of Mg/Ca ratio along a cross section of the CaCO₃ shell of pāua can contribute to the high temporal reconstruction of ocean temperatures and climate change.

New geochemical techniques have been developed to measure trace element chemistry of CaCO₃ shells in modern pāua using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) in order to calibrate shell chemistry with environmental conditions. Pāua shells were collected from five different localities around New Zealand. The samples were analysed using a deep ultraviolet beam ablating at 25µm spot sizes every 400µm across a transect of the shell. The Mg/Ca ratio data obtained from the CaCO₃ shell of pāua showed variance that emulated the seasonal temperature pattern of the ocean during its growth. Further analysis also showed distinct Mg/Ca ratio variation in shells sampled from different latitudes reflecting seawater of temperatures ranging from 7°C to 17°C. Additionally, the monitoring of other elements including barium, aluminium, lead and zinc may be able to reveal the past frequency of storm events that deliver sediment into the oceans, changing levels of environmental pollution and potentially develop site-specific forensic fingerprints that can be used to combat illegal exploitation of pāua.

A PRONIVAL ("PROTALUS") RAMPART IN THE TARARUA RANGE, NORTH ISLAND

J. Williams & M.S. Brook

School of People, Environment & Planning, Massey University, Palmerston North
m.s.brook@massey.ac.nz

A pronival (protalus) rampart is a ridge of predominantly coarse detritus, usually located at or near the foot of a talus slope, that has formed through the accumulation of debris along the down-slope margins of a perennial firn-field following supranival gravitational transport. We present evidence for a relict pronival rampart on the southeast-facing side of Dundas Ridge in the eastern Tararua Range, North Island. Our interpretation is based on geomorphic similarities with actively forming landforms in alpine environments, and on the congruence with criteria widely believed to be diagnostic of relict pronival ramparts elsewhere. The rampart is located at 1200 m at the base of a talus slope on a steep backwall, and comprises a broad low ridge, c. 250 m long and c. 25 m wide, that traverses the slope in a northeast/southwest direction, approximately parallel to the surface contours. The ridge is asymmetric in cross-profile, with a steep (max. 40°) distal slope and a low gradient (<20°) proximal slope, and is semi-arcuate in plan-form. Throughout its length, the feature is composed of open-work debris with variable amounts of interstitial fines. Component clasts are very angular (63%) or angular (31%), and their maximum *b*-axis length is 1.5 m, indicating the rampart material has undergone passive transport. The rampart crest is 60-70 m from the base of the talus slope, and this has two implications: (1) reconstructing the upper surface of the firn-field from the rampart crest to the base of the upslope rockwall, a firn-field gradient of 28° to 35° can be estimated, greater than the minimum value (20°) proposed in previous studies; (2) a firn-field of this size may be expected to alter the form of the rampart due to increased basal shear stress, encouraging creep of firn and possibly basal sliding.

GROUND-PENETRATING RADAR STUDY OF PLEISTOCENE RELICT FOREDUNES AT MATAKANA ISLAND, BAY OF PLENTY

J. Williams & M.S. Brook

School of People, Environment & Planning, Massey University, Palmerston North
parabolicflow@gmail.com

Matakana Island forms a c. 24 km long barrier island between the Bay of Plenty and Tauranga Harbour, which it encloses. The island is of two distinct parts, with the larger seaward part comprising a Holocene sand barrier, extending parallel to the shoreline, and a harbourward (Pleistocene) part, adjoining the centre of the Holocene barrier. The Pleistocene part of the barrier consists of three terraces at c. 10, c. 40 and c. 70 m above sea level, although the precise process-origins and significance of the features are unknown. We focus on the relatively flat lowest (1.0-1.5 km wide) terrace, as oblique aerial photography indicates the presence of subdued ridges (amplitude c. 1 m) trending NW-SE, parallel to the current coastline. An investigation of this lower terrace using a 100 MHz pulseEKKO PRO ground penetrating radar (GPR) along a c. 1 km SW-NE profile normal to the axis of the subdued ridges was undertaken. Following topographic correction, the profile revealed a continuous undulating reflector at c. 8-12 m depth, which corresponds with the low ridges visible on the surface. The ridge-and-swale nature of the reflector, coupled with the surface topography indicates it represents a relict foredune plain, mainly below present-day sea level. The age of the relict foredune plain is intriguing, with a maximum age c. 780,000 due to the absence of Te Puna Ignimbrite, which is present on the higher terraces. Published maps indicate the lowest terrace is covered by lacustrine beds of the Matua Subgroup (minimum age c. 220,000 yr), yet it is difficult to reconcile the survival of ridge-and-swale foredune morphology under several metres of lacustrine deposits, suggesting that a tephra origin for the coverbeds is more likely. Nevertheless, the presence of a Pleistocene foredune plain slightly below present-day sea level indicates no significant uplift, and possibly minor subsidence in the area.

ZIRCON AGE AND COMPOSITIONAL PATTERNS IN TVZ SILICIC VOLCANIC ROCKS

C.J.N. Wilson¹ & B.L.A. Charlier²

¹SGEES, Victoria University, PO Box 600, Wellington

²Dept. of Earth & Environmental Sciences, Open University, Milton Keynes, UK.

colin.wilson@vuw.ac.nz

Age dating of zircon by either U-Th disequilibrium or U-Pb techniques, together with associated trace element analyses (Hf, Ti, REE) has opened up new perspectives on the timing, origins and tempo of Quaternary silicic magmatic and volcanic processes in the central Taupo Volcanic Zone (TVZ). U-Th disequilibrium model-age dating using multi-grain TIMS techniques as well as single-crystal ion-probe (SHRIMP-RG) analyses has been applied to units including and younger than the ~61 ka Rotoiti event, and U-Pb dating to rocks including and older than the 322 ± 7 ka Matahina eruption deposits. Comparisons between the records given by tephrochronological and petrological studies of erupted rocks and zircon age data allow contrasting the patterns of magmatism versus volcanism to be distinguished. New information that has arisen from this work includes the following. (1) Recognition of zircons (and other mineral phases) as phenocrystic, antecrystic or xenocrystic, depending on their age and/or compositional relationships to the host magma and the age of the eruption. (2) Understanding of the extraordinarily rapid rates of accumulation of the ~530 km³ melt-dominant body for the 27 ka Oruanui supereruption and its comparably rapid destruction. (3) Identification of xenocrystic zircons and their fingerprinting to host protoliths, at the same time demonstrating a role for wholesale crustal melting in the generation of silicic magmas below Taupo and a short time period (<1-10 years) between crustal melting and eruption. (4) Use of trace element patterns versus age to monitor the thermal and compositional regimes experienced by large zoned zircons. (5) A first-order contrast between the magma dynamics of Taupo and Okataina volcanoes that complements information from whole-rock and crystal-specific studies and suggests that the two systems are linked through large-scale tectonic processes.

ZIRCON AGE PATTERNS IN TVZ BURIED AND HYDROTHERMALLY-ALTERED ROCKS: A PROGRESS REPORT

**C.J.N. Wilson¹, B.L.A. Charlier², J.V. Rowland³, P.R.L. Browne³, S.D. Milichich⁴
& G. Bignall⁴**

¹SGEES, Victoria University, PO Box 600, Wellington.

²Dept. of Earth & Environmental Sciences, Open University, Milton Keynes, UK.

³School of Environment, University of Auckland, PB 92019, Auckland.

⁴GNS Science, Private Bag 2000, Taupo.

colin.wilson@vuw.ac.nz

Zircon crystallisation-age dating using U-Pb systematics on the SHRIMP-RG ion microprobe provides a tool to identify and correlate buried, hydrothermally altered silicic rock units in the central Taupo Volcanic Zone (TVZ). Previously, the major rock units were mapped with local names at individual fields, and only ignimbrite interpreted to be a correlative of the ~340 ka Whakamaru-group of eruptions had been identified at more than two geothermal fields. Crystallisation-age spectra have been obtained from deposits as young as ~320 ka, allowing any zircon-bearing rocks at or below the level of the Whakamaru-group of ignimbrites to be dated. Fresh surficial lithologies have their crystallisation-age spectra determined on zircons extracted from single pumice clasts, while analysed material from geothermal fields comes from core and/or cuttings (the former wherever possible, to eliminate contamination from downhole mixing). Ages have been obtained so far from representative samples at seven geothermal fields. At Mangakino, age dating has prompted revision of petrographic correlations and recognition of ~1.8 km of intracaldera fill ignimbrite from the 1 Ma Kidnappers/Rocky Hill pair of eruptions. At Waiotapu, the oldest deposits reached by drilling are 1.45-1.55 Myr old at ~1.1 km depth, at Kawerau they are >1.45 Myr old below ~0.65 km depth, but at Mokai and Wairakei even at depths exceeding 2.5 km the deepest ignimbrites are ≤1 Myr in age. Inferred depths to the dated horizons allow first-order estimates of the patterns and amounts of long-term subsidence over parts of the central TVZ and define major basin structures. Age patterns of inherited zircons allow assessment of magmatic or volcanic histories, but this is restricted by the nature of the material available (pumice versus cores versus cuttings) and uncertainties about source locations for many of the ignimbrite units.

VOLCANIC ASH TESTING (VAT) LABORATORY

**T. Wilson¹, D. Johnston², J. Wardman¹, G. Wilson¹, C. Stewart¹,
V. Sword-Daniels¹, J. Cole¹, P. Bodger¹, G. Leonard² & S. Cronin³**

¹Natural Hazard Research Centre, University of Canterbury, Christchurch.

²Joint Centre for Disaster Research, GNS Science/Massey University, Wellington.

³Volcanic Risk Solutions, Massey University, Palmerston North.
thomas.wilson@canterbury.ac.nz

Volcanic ashfall causes impacts to many societal elements. Impact intensities vary from minor nuisance to significant disruption or even total destruction. Modern volcanic risk assessment and strong end-user information needs during an eruption crisis requires the research community to provide robust estimates of what impacts are likely to occur. This presents a significant challenge given the wide range of physical and chemical properties of volcanic ash, and the rapid growth and evolution of modern society.

To fulfil this need the New Zealand Volcanic Ash Impacts Study Group (VISG) and collaborators have aimed to undertake a sustained and systematic approach to volcanic impact assessment for: critical infrastructure: electricity, water supplies, wastewater, land and air transport, telecommunications; ash cleanup and disposal; primary industries, including agriculture; social impacts; and emergency management. VISG has used a research model of undertaking reconnaissance trips to areas impacted by volcanic ash fall, with a focus of transferring this knowledge to end-users in New Zealand. This approach has strengthened and diversified our understanding of volcanic ash impacts, particularly as modern society and technologies evolve. However, it rarely allows detailed research to solve exactly how and why observed impacts occur.

Therefore we introduce the Volcanic Ash Testing Laboratory (VAT Lab). VAT Lab is a consortium of research organisations investigating the impact of volcanic ash fall. It aims to provide more quantitative information for end-users through performance testing of critical components under varying intensities and types of volcanic ash. Crucially, it also provides a setting for experimentation of potential mitigation methods. This paper will present research on ash impacts to high-voltage electrical transmission systems, water and wastewater systems, laptop computers, air-conditioning units and residential roofs.

DEALING WITH HOLE COLLAPSE DURING DRILLING IN THE WAIRAKEI FIELD

R. Winmill¹ & E.L.D. Fooks²

¹Contact Energy, Private Bag 2001, Taupo

²GANZL, 281 Bucklands Beach Rd, Auckland
ralph.winmill@contactenergy.co.nz

Recent drilling within the Wairakei Geothermal Field has been plagued with significant instances of hole collapse. This has added significant time, cost and risk to the well construction projects. Historic techniques for stabilising collapsing formations using cement plugs and maintaining full mud circulation have proven to be inadequate for curing these collapse problems. New solutions were sought and trialled to drill past these hole collapse zones and complete the well. One solution used successfully was to run an intermediate string to fit between two planned casing sizes, to provide temporary stability. Another solution trialled was to use Reaming with Casing (RwC) and Drilling with Casing (DwC) techniques to get casing past the problem zones. This was trialled on an increasing scale of complexity and some significant lessons were learned. Contact has also improved its techniques for identifying these zones by using a Standardised ROP method and seeking for a better geological understanding and identification of these problem zones as drilling is being undertaken.

DUST AND IRON FLUX TO THE ROSS SEA, ANTARCTICA

V.H.L. Winton^{1,2}, **G.B. Dunbar**¹, **N.A.N. Bertler**^{1,2}, **M-A. Millet**³, **B. Delmonte**⁴

¹Antarctic Research Centre, Victoria University of Wellington, PO Box 600, Wellington.

²Geological and Nuclear Sciences, PO Box 31 321, Lower Hutt.

³School of Geography, Environment and Earth Sciences, Victoria University of Wellington, PO Box 600, Wellington.

⁴Dipartimento di Scienze dell'Ambiente e del Territorio, Università degli Studi di Milano-Bicocca, Milano, Italy.
holly.winton@vuw.ac.nz

Each summer the iron-limited waters of the McMurdo Sound (MS) Polynya, in the southwest Ross Sea, bloom with phytoplankton. This phenomenon is thought to be stimulated by the addition of bio-available Fe leached out of aeolian dust from local and/or global sources in the southwest Ross Sea, each summer as the sea ice melts. The bio-availability of Fe is influenced by several parameters. Amongst them are the dust flux, particle size distribution and provenance, which all remain largely unaddressed. Consequently, the role of aeolian Fe in the biogeochemical cycle of plankton growth remains to be quantified.

To provide estimates of Fe flux to the Ross Sea we have analysed the dust content in 50 surface snow samples and 5 shallow firn cores. Our results show the dust flux for this region (average 11.8 g/m²/yr) is higher by at least 2 orders of magnitude than predicted in global dust distribution models (0.001-0.2 g/m²/yr). For this reason we suggest that locally-derived dust dominates in MS and, provided its bio-available Fe content is high enough, is likely to trigger phytoplankton blooms.

Future work will be directed towards two aims: first, determine sources of dust collected in snow samples from sea ice in MS and from sediment traps across the Ross Sea using Pb isotope ratios; second, quantify the amount of soluble Fe in the surface snow dust samples as a proxy for the maximum amount of bio-available Fe released in the southwest Ross Sea each summer.

FAULT ASSESSMENT BY GRAVITY AND GPR INVESTIGATIONS FOR A HOSPITAL IN WHAKATANE

S. Woelz¹ & **D. Beetham**² & **J. Begg**²

¹SGEES, Victoria University Wellington, PO Box 600

²GNS Science, PO Box 30368, Lower Hutt, New Zealand
swoelz@vuw.ac.nz

Hospitals in urban areas are key facilities which should be undamaged and fully functional after natural disasters such as earthquakes, storms/floods, volcanoes and tsunamis. Because of concerns about the location of the active Whakatane Fault through the town of Whakatane and its possible proximity adjacent to or even under a hospital site, Ground Penetrating Radar (GPR) and gravity surveys were carried out. GPR as a high-resolution geophysical method is widely used to investigate fault zones. It helps to visualise sedimentary structures related to recent deformation and resolves features from a few centimetres to several metres. Whereas gravity gives the possibility of locating faults in a wider area and to a greater depth.

GPR and gravity compared to other geophysical methods are non-intrusive, fast and easily deployed and therefore powerful tools in urban areas. Comparably fast data analysis and interpretation makes them good tools for rapid field assessment.

It was anticipated that gravity surveys along several lines near the hospital should clearly show the location of a sub-surface fault step (several hundred metres high) in the underlying basement greywacke rock and its dip angle. The location of this step through Whakatane town is important for planning. The GPR survey was expected to show offset layers in the top 10m and thus indicate if the "terrace feature" on the western side of the hospital is an actual fault scarp.

The gravity survey indicates that the major sub-surface displacement of the greywacke basement surface, which we model as the location of the main strand of the Whakatane Fault, is located 550-750 m east of the Hospital site.

The GPR survey shows that the ~2m high "terrace" feature on the western side of the Hospital site is not a fault scarp of the Whakatane Fault. Rather it is a river terrace relating to the modified channel edge of an abandoned course of the Whakatane River.

GEOTECHNICAL OBSERVATIONS FOLLOWING THE DARFIELD EARTHQUAKE

**L. Wotherspoon¹, M. Cubrinovski², R. Green³, R. Orense¹, M. Pender¹, S. Ashford⁴,
T. Hutchinson⁵, E. Kavazanjian⁶, B. Cox⁷, T. Algie¹, M. Jawad Arefi², M. Taylor², K.
Robinson², B. Bradley², T. Larkin¹ & E. Bowman²**

¹University of Auckland, Private Bag 92019, Auckland.

²University of Canterbury, Private Bag 4800, Christchurch

³Virginia Tech, Blacksburg, VA 24061, USA

⁴Oregon State University, Corvallis, OR 97331, USA

⁵UC San Diego, La Jolla, CA 92093, USA

⁶Arizona State University, Tempe, AZ 85287, USA

⁷University of Arkansas, Fayetteville, AR 72701, USA

l.wotherspoon@auckland.ac.nz

Following the September 4, 2010 Darfield earthquake, a team of New Zealand and American based geotechnical engineers carried out a coordinated reconnaissance effort in the affected region. This was a significant event in terms of liquefaction and lateral spreading, resulting in damage to the built environment across the region. The most affected areas were the Christchurch suburbs of Dallington, Avonside, and Bexley, the outlying suburbs of Halswell, Spencerville, Brooklands, and the town of Kaiapoi. The extent of the liquefaction and lateral spreading may have been so widespread because of the high water table resulting from a very wet winter season.

One of the most important observations to come out of this event was the extent of lateral spreading and post-liquefaction differential settlement damage to residential structures. Many structures were left uninhabitable as a result of these large movements. Damage to the sewer and water supply network was also significant, with lateral movement and floating of the pipes due to liquefaction. Because of breaks in the pipes, large volumes of liquefied sand and water also entered the system, requiring a significant effort to remove.

While not as extensive, there was also damage to roads, bridges, railroad embankments, and stop banks. Cracking in roadways from ground movement and slumping of sections of roads adjacent to waterways was evident, while movement of railroad embankments caused buckling of tracks. Road bridge approaches were affected due to lateral spreading, while lower strength footbridges suffered structural damage due to the compressive forces from this spreading. Liquefaction was widespread along the Kaiapoi River, with large cracking and subsidence in the stop banks. The movement of the path of the Waimakariri River prior to construction of the stop bank network in the mid 1800's was also shown to correspond to some areas of liquefaction.

DESIGNING FOR SAFE OUTCOMES – WHY WE SHOULD DO MORE

R. Wright

Parsons Brinckerhoff

Designers have always considered safety an integral component of their activity. Safety is traditionally canvassed in key stages of design. However, many jurisdictions have implicit or explicit requirements for design-stage consultative processes that have not been traditional activities in many industry sectors. The paper discusses the additional processes, why they have been enshrined in legislation, how to judge an appropriate amount of effort to comply and why the end-result can be a wonderful justification of the effort exerted.

VOLATILE ELEMENTS IN VOLCANIC ROCKS FROM SOUTHERN KERMADEC ARC VOLCANOES AND BASINS: IMPLICATIONS FOR HYDROTHERMAL PROCESSES

**R.J. Wysoczanski¹, M.R. Handler², C.I. Schipper³, J. Creech², M.D. Rotella²,
C.J.N. Wilson² & R.B. Stewart³**

¹National Institute of Water & Atmospheric Research, Private Bag 14901, Wellington.

²SGEES, Victoria University of Wellington, PO Box 600, Wellington.

³Soil & Earth Sciences, INR, Massey University, Palmerston North.
r.wysoczanski@niwa.co.nz

Seafloor massive sulphide (SMS) deposits in oceanic subduction zones, including the Kermadec arc, are becoming a valuable commodity, viable as a source of precious metals. However, the ultimate source of sulphur and metals in SMS deposits remains unknown. Are magmatic melts/fluids/gases sufficiently enriched in these elements to produce SMS deposits, or are the metals scavenged from the surrounding oceanic crust or volcanic edifice and concentrated into deposits via hydrothermal liquid/gas flow? Similarly, are the metals (Fe, Cu, Au, Ag, Pt) transported to the deposits by liquids or supercritical dense fluids (rich in H or Cl) or gases (rich in S or C)? Understanding the source and mechanism of transport is important in ascertaining how and where SMS deposits occur, and to understand the redistribution of elements among the Earth's mantle, crust, oceans and atmosphere.

Here we present volatile element (H, C, S, Cl) data from selected arc front volcanoes, and arc-front and back-arc basins of the southern Kermadec Arc. Both olivine-hosted melt inclusions and host pillow glass rims have been analysed so as to allow the concentration of these elements in mantle-sourced magmas and their final concentration in volcanic lavas to be assessed. These data will constrain the role of degassing in the distribution of these elements in magmatic systems and place constraints on the budget of mantle-sourced precious metals transported by fluids and gases in volcanic systems. Because the samples are sourced from both hydrothermally active and inactive regions, these results have implications for the distribution and intensity of activity of hydrothermal vents between volcanic front-arc volcanoes and front-arc and back-arc basins. Constraints on the metal budgets will also provide insights into whether SMS deposits are solely sourced from the mantle or involve scavenging of pre-existing crustal material.

AN UPDATE ON THE MODELLING OF THE WAIRAKEI-TAUHARA GEOTHERMAL SYSTEM

A. Yeh¹, M.J. O'Sullivan¹, J. McDowell¹, W.I. Mannington² & K. Brockbank²

¹Dept. of Engineering Science, University of Auckland, Private Bag 92019, Auckland.

²Contact Energy Limited, Private Bag 2001, Taupo.
cyeh015@aucklanduni.ac.nz

Modelling of the Wairakei-Tauhara geothermal field, New Zealand, has been on going for a number of years. The reservoir model, based on the TOUGH2 simulator, has been updated and re-calibrated with the advancement of computer hardware and modelling techniques and the availability of new field data.

In the last few years the field operator, Contact Energy Limited, has become interested in the Tauhara sector of the system and has drilled several new wells. These wells have provided down-hole temperatures and information about the geological structure at Tauhara.

In previous version of the model some of the Tauhara sector was not accurately represented, but this approximation was not important because the connection across to Wairakei is weak. Now because of Contact Energy's new priorities it has become important to better represent the Tauhara sector in the model and the new data has made it possible to carry out calibration.

As well as improving the model at Tauhara other improvements have been made. For example the model has been deepened so that it includes more of the large-scale convective system and is less dependent on assumptions about deep recharge.

The new model matches well most of the data available on down-hole temperatures and historical changes in production enthalpies and reservoir and monitor pressures. The model has been used to simulate six future scenarios for production and injection at both Wairakei and Tauhara.

OPTIMIZATION OF STEAM FIELD CONCEPTUAL DESIGN WITH POWER PLANT

C. Zhang

PB New Zealand Ltd, PO Box 3935, Shortland Street, Auckland.
zhangch@pbworld.com

The geothermal steam field, including production wells, steam separators, steam scrubbers and piping network, provides the energy supply system for geothermal power generation. The goal of the geothermal steamfield design is to optimise the cost/benefit of this energy supply system.

This paper presents a method for steam field design optimization with a power plant optimization model, which achieves the maximum cost/benefit for a geothermal power generation project over the whole project life.

The model developed is able by a series of iterations to not only provide the optimum turbine inlet pressure for the development, but also produces an optimum conceptual design including two phase or/and single phase pressure drops, fluid flows and pipeline sizes for a steam field well and piping network, based upon the known deliverability curves for each production well. The pipe sizes and pressures are all optimised in order to provide the best life cycle cost/benefit of geothermal power generation application.

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